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THREE SMALL UNIT SHORT TERM
FORCE ON FORCE ATTRITION MODELS
WITH LOGISTICS CONSIDERATIONS

by

Dean E. Fish

March 1987

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Three Small Unit Short Term Force on Force Attrition Models with Logistics Considerations

by

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requirements for the degree of

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Three related simulation models based on modified Lanchester theory are examined. The models allow consideration of various aspects of logistics to be incorporated into a battle scenario. The first model allows for an overall general logistics percentage factor that must remain the same for each input throughout a hypothetical engagement. The second model has the additional capability to allow for varying logistics percentages. The last model includes the advantages of the second model plus two intermediary steps and also allows for resupply. The two intermediary steps discuss aspects of two additional models that will not be fully developed in this thesis. They show the procedure used in the development of the resupply considerations in the last model. These models are general in application, and they are designed for small unit short term scenarios. This thesis is demonstrative in nature, and its purpose is to demonstrate a basis of techniques and computer programs for incorporating logistics considerations into a hypothetical combat environment that can be later modified and structured for user specific needs.

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THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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I. INTRODUCTION AND BACKGROUND

A. INTRODUCTION

Historically logistics have been the stepchild of operators and modelers. In many cases logistics considerations appear to have been included in models merely as afterthoughts. Most models take into account the consumption of logistics, but few adequately take into account explicit resupply or attrition of logistics units. This is especially true of mid-scale models. Small scale models with such considerations are almost non-existant. Some large scale models do play these important considerations, but they require massive set up times ranging from several days to several months. These models are not practical for small unit use. Hence there is a great need for small scale models that play various logistics factors. In an attempt to satisfy this need, three related models have been developed that take into account various logistics considerations on a small scale for use by lower level units.

This thesis begins with a discussion of the importance of logistics and an introduction to Lanchester theory provided as background. The following three chapters are devoted respectively to the three models presented in this thesis, and they are designed to illustrate how Lanchester models can be formulated to include logistics considerations. Each chapter begins with an introduction of the model. The introduction is followed by an illustration, a discussion of the model and its associated assumptions and parameters, and finally by a discussion of the computer programs including a user's manual and a list of variables as well as listings of the actual programming code. The final chapter presents additional areas for future consideration and a short summary.

B. LOGISTICS

With respect to the military, Webster defines logistics as: "The procurement, maintenance, and transportation of military material, facilities, and personnel" [Ref. 1: p. 497]. In a broad sense this represents a fair description of logistics. Perhaps a more accurate portrayal of logistics might be:

> The science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, logistics pertains to those aspects of military operations which deal with (a) design and development, acquisition, storage, movement, distribution, maintenance, evaluation, and disposition of

material; (b) movement, evacuation, and hospitalization of personnel; (c) acquisition or construction, maintenance, operation, and disposition of facilities; and (d) acquisition or furnishing of services. [Ref. 2: p. 401]

One should gather from these definitions that the realm of the logistics field is far reaching and extremely complex. It touches nearly every aspect of the military in one way or another. However, the scope of this thesis will be limited to the military campaigns and operations aspects of logistics or combat service support.

C. COMBAT SERVICE SUPPORT

Combat service support is that assistance provided to operating forces which have a primary mission of participating in combat or combat planning. The Marine Corps subdivides combat service support into 24 functions as outlined in Table 1. [Ref. 3: pp. 1-2 to 1-10]

TABLE 1

COMBAT SERVICE SUPPORT FUNCTIONS

Supply	Food Services
Maintenance	Postal
Transportation	CSS Training
Engineer Support	Military Police
Landing Support Operations	Exchange Services
Medical	Passenger and Freight Transportation
Dental	Legal
Graves Registration	Morale, Welfare, Recreation
Material Handling	Civil Affairs
Financial Management	Administration
Automatic Information Systems	Ecclesiastical Services
Embarkation	Band

Each of the above functions are carefully intertwined to form the overall combat logistics effort, but some functions play a more critical role than others.

D. COMBAT SERVICE SUPPORT AND HISTORY

History has shown that the influence of combat service support considerations on the outcome of battles and the general importance of these considerations in the combat environment should be strongly emphasized. A vivid classical example of this involved the careers of Napoleon Bonaparte, the Duke of Wellington and the Battle of Waterloo. Napoleon was traditionally educated in war, and his attitude towards logistics was one that war could always be made to support war or living off the land one conquered. Napoleon's brilliant military career was pock marked with disasters

such as the Battle at Acre, the Russian Campaign, and his eventual defeat at Waterloo primarily due to his disregard for logistics considerations and his failure to learn from his logistical mistakes. During his campaigns, his armies were consistently low on rations, water, powder, ammunition, medical supplies, and clothing. On the other hand, the Duke of Wellington held a firm grasp of the value and importance of logistics. From his first taste of battle on the Elms, and through his experiences in India and Portugal, he refined his logistical prowess and unlike Napoleon learned from his mistakes. His armies were seldom left wanting for sustenance or military supplies. As a result, the Duke of Wellington was able to better the efforts of Napoleon's Marshals and defeat Napoleon at Waterloo. [Ref. 4: pp. 3-13] Major Hargreaves superbly summarizes the point made here when he wrote:

> In a war of materiel, such as modern science has inflicted on the fighting man, a high standard of morale can only be the outcome of a well integrated, smoothly working logistical organization. Whereafter, if we take the quartermaster as symbolizing all that we mean by logistics, there can be no gainsaying the profundity of Erwin Rommel's dictum that, "Before the fighting proper, the battle is fought and decided by the quartermasters." [Ref. 4: p. 13]

Erwin Rommel's career is well known and is yet another classic example of how inadequate logistics planning and support in a combat environment can turn the tides of battle.

E. SUPPLY SUPPORT

Although all 24 combat service support functions outlined in Table 1 play a roll in the overall combat logistics effort, the underlying factor of most historical logistical disasters appears to have been that of inadequate supply support. Regardless of how good a fighting unit is and how powerful their weapons are, they will be ineffective if they don't have food, water, ammunition, fuel, and so forth to fight with. So far there have been several references to combat supplies, but no explicit definitions as to exactly what they are. There currently exist 10 classes of supplies within the department of defense which are briefly outlined below:

1. Class I - Subsistence Items
2. Class II - Clothing, individual equipment, tentage, tools, administrative and housecleaning supplies
3. Class III - Petroleum, lubricants, oils, compressed gases, coolants, coal, etc.
4. Class IV - Construction materials
5. Class V - Ammunition of all types

6. Class VI - Personal demand items
7. Class VII - Major end items - tanks, artillery, LAV's, vehicles, mobile machine shops, etc.
8. Class VIII - Medical and dental materials
9. Class IX - Repair parts and assemblies
10. Class X - Material to support non-military programs, agriculture and economic development

F. MODELING WITH LOGISTICS AND PURPOSE OF THE THESIS

The importance of logistics, combat service support, and supply support as discussed previously is not a new idea. Yet until recently, these support considerations have been considered backseat factors to be handled at a later time. In the last couple of decades an increased emphasis has been placed on defining, organizing and integrating these ideas into the combat scenario [Ref. 5: p. 5]. Commanders as well as operations and logistics staffs are becoming increasingly interested in pre-combat insight of what impact logistics support factors are going to have on the outcome of a battle. There are a number of computer simulation models that include logistics factors in predicting the outcome of a battle scenario. For example, IDAHEX is an interactive computer simulation model for a conventional two sided land warfare situation at the theater level where the consumption of supplies and other logistics factors can be played. This is a complex program that requires the use of a lengthy and detailed user's manual and a mainframe computer. [Ref. 6: pp. iii-v] The use of such a computer model could prove invaluable to a commander and/or his staff in prepartion for combat or for training. If such a model or a series of smaller less complex models could be condensed to the personal computer level and provided permanently to lower level unit commanders for daily use in training, while on deployment, or for actual combat preparation, the increased awareness of combat service support considerations could have a substantial impact on unit readiness. From what history has taught us, it can be reasoned that such combat units might well be more effective and efficient in a combat environment. The purpose of this thesis is to develop and demonstrate simplified computer modeling techniques that can be easily modified and implemented by units to suit their logistics and planning purposes. These modeling techniques describe a combat scenario with logistics considerations. They are written in the BASIC language and are designed for use on personal computers.

G. THE DEVELOPMENT OF LANCHESTER EQUATIONS

1. Background

The techniques and models demonstrated in this thesis can be modified to suit specific purposes. In order to implement these modifications, it is necessary to have a basic background knowledge and understanding of the mathematical theory used in designing the models presented here. In combat engagements the victorious force is usually the one which has the largest combat strength remaining at the termination of a conflict. Looking at it from another view, with all other things assumed equal, the force with the highest attrition is usually the loser. This phenomenon is conveniently modeled by using ordinary differential equations. One application of ordinary differential equations used in such military applications are the Lanchester equations first proposed by F. W. Lanchester who postulated their use in 1914. Lanchester's major contribution was to translate the principle of concentrated firepower of modern warfare into mathematical terminology. Since models are representations or approximations of real situations used to predict outcomes, we have the more general term of Lanchester-type models. To summarize, Lanchester-type models are systems of ordinary differential equations that model the involvement of military forces engaged in combat. One purpose of applying the model is to predict the outcome of the conflict. [Ref. 7: pp. 52-53] Another purpose is to calculate the remaining sizes of the forces at various stages of the conflict and to examine how the outcome might vary by changing the input.

There are two classical forms of Lanchester models: stochastic and deterministic. Stochastic models represent elements of uncertainty or chance. The outcome of a battle scenario is not known with certainty, and therefore there are probabilities of each force becoming victorious. In deterministic models, the victorious force is uniquely determined and known with certainty. There is no element of chance in that given input conditions will always produce the same results. [Ref. 7: pp. 4-6] This thesis will be concerned with deterministic Lanchester models.

Since 1914 many different laws of Lanchester model theory have been developed and widely used. Two such models lead to results called the square law and the linear law.

2. Square Law

Lanchester hypothesized that for any two given forces, the rate that one force attrites the other is proportional to the size of the former. Hence, the casualty rate of

a particular force is proportional to the number of enemy combatants. Consider a scenario where B(t) is the number of combatants in the Blue force at time "t", and let the initial size of the Blue force at time $t=0$ be $B(0)=B_0$. Then $dB(t)/dt$ is the change of the size of the Blue force with respect to time or the attrition rate of the Blue force. B(t) is decreasing and therefore B' is negative. Let R(t) denote the number of combatants in the Red force at time t, and let the initial size of the Red force at time $t=0$ be $R(0)=R_0$. Then $dR(t)/dt$ is the change of the size of the Red force with respect to time or the attrition rate of the Red force. R(t) is decreasing and R' will also be negative. Thus Lanchester postulated the following model:

$$dR(t)/dt = -bB(t)$$
$$dB(t)/dt = -aR(t) \qquad \text{(eqn 1.1)}$$

where "a" and "b" are positive constants of proportionality or more commonly known today as Lanchester attrition rate coefficients or force efficiency measures. In this thesis, the term combat effectiveness is defined to be the square law attrition rate coefficient. They are used in both the square law and linear law to represent each force's firepower or killing ability against the opposing force's sustainability or vulnerability. For example, $a < b$ implies that the Blue force has more killing firepower per combat entity than the Red force or the Red force is more vulnerable to fire than the Blue force. For the square law, the units of "a" and "b" are number of Blue casualties/(one Red shooter x time) and number of Red casualties/(one Blue shooter x time) respectively. Algebraically manipulating Equation 1.1 yields:

$$d(B(t))/d(R(t)) = aR(t)/bB(t) \qquad \text{(eqn 1.2)}$$

Integrating Equation 1.2, where the inital sizes of the Blue and Red forces are B_0 and R_0, respectively, yields:

$$b(B_0^2 - B(t)^2) = a(R_0^2 - R(t)^2) \qquad \text{(eqn 1.3)}$$

Equation 1.3 is known as the state equation for the square law, due to the presence of the squared force level terms in the equation. The square law is also known as the aimed fire model due to its applicability to a scenario where both the Blue and Red

forces are aiming their weapons at one another, and complete target acquisition is assumed throughout the battle. [Ref. 7: pp. 52-63] The effects of suppression, leadership, fatigue, etc. might be modeled by allowing the attrition rate coefficients "a" and "b" to vary appropriately with time. This idea will not be considered in this thesis.

3. **Linear Law**

Lanchester also considered the case where the casualty rate of a particular force is proportional to the number of combatants of both forces involved in the battle. Given the scenario above, this is modeled as follows:

$$dR(t)/dt = -bR(t)B(t)$$
$$dB(t)/dt = -aB(t)R(t) \qquad \text{(eqn 1.4)}$$

Algebraically manipulating equation 1.4 as before yields:

$$d(B(t))/d(R(t)) = a/b \qquad \text{(eqn 1.5)}$$

Integrating the equations yields the state equations for the linear law:

$$b(B_0 - B(t)) = a(R_0 - R(t)) \qquad \text{(eqn 1.6)}$$

Equation 1.6 is known as the linear law due to the linearity of the force level terms in the state equations. "a" and "b" are Lanchester attrition rate coefficients or force efficiency measures as described earlier, but with different units. For the linear law, the units of "a" and "b" are number of Blue casualties (one Red shooter x one Blue target x time) and number of Red casualties (one Blue shooter x one Red target x time) respectively. The linear law is also known as the area fire model due to its applicability to a scenario where both the Blue and Red forces are firing weapons into the others general area and not at specific targets. [Ref. 7: pp. 52-63]

4. **Accuracy of Numerical Solution for the Square Law**

If the user were to graph the actual strength of one of the forces, say B(t), versus time, B(t) would plot as a continuously decreasing function as time increases. Imagining such a plot, take the time axis and partition it into "delta t" time increments. At each "delta t" time increment boundary, compute the slope using the Lanchester square law equations. Then extrapolate linearly the B(t) curve to the next "delta t"

time boundary. Recompute the slope and extrapolate again. If this process is continued, the result is a polygonal path which is an approximation of B(t). A question might arise as to how small the "delta t" time increments have to be in order to obtain a reasonable solution. Since B''(t) is positive throughout the time interval, there may be an accumulation of error in the approximation of B(t). The smaller the "delta t" time increment the more accurate the approximation will be. However, if the "delta t" time increments are too small when the process described above is carried out in a computer program, the run time can be excessive. Thus there is a trade-off between computer program run time and accuracy, and the user must determine what the acceptable compromise will be for each situation. For the demonstrational purposes of this thesis, the "delta t" time increments will be refered to as step time increments. An error analysis was conducted for the Lanchester square law, and a "delta t" time increment of one second was found to be more than adequate to give sufficient accuracy for the methods used in this thesis.

H. SPECIAL COMMENTS

The three models and programs presented in this thesis are all based on Lanchester-type models that have been modified to include logistics considerations. Equations leading to the square law and linear law can easily be solved analytically, but when the logistics modifications are included analytic solutions are not trivial, so numerical computer solutions are used. Each successive model in the following chapters is an expansion of the previous one which becomes more detailed and explicit in nature. Each model will be discussed in detail in a respective chapter. Prior to discussing the models and detailing the programs used to solve them, there are several important observations that need to be stated:

1. The models and programs demonstrated are designed to be used and modified at the small unit level by command or staff personnel having some familiarity with operations analysis techniques.

2. The users should have access to a personal computer that can run the BASIC software preferably with a high speed capability.

3. The three models and programs presented in this thesis are demonstrative and general in nature. They are not tailored to fit or model any one specific scenario or type of unit. The intent is to show possible techniques of incorporating logistics factors into the modeling of combat scenarios and how the models and computer programs may be designed to fit a given problem. However, it may be appropriate to use some of the programs directly under selected conditions.

4. Each of the three models contains two subprograms. The first subprogram is an input program which interacts with the user to set up the input data. The second program is the main program which receives the data from the input program and then provides output on the screen.

5. The programs are documented so the user can see what is being accomplished in the program by reading the internal comments.

6. Variables were named so as to be easily identifiable. Lists of variables are provided with each of the main computer programs.

7. In general, it is advisable to read this entire document prior to attempting to implement programs similar to those presented in this thesis. The models and computer programs are dependent on one another, and it may be necessary to fully understand the earlier models and programs before attempting more difficult ones.

II. MODELING WITH CONSTANT LOGISTICS PERCENTAGES

A. INTRODUCTION

This model and computer program is the first of the three to be presented in this thesis. Several assumptions are required in this model, but it is very flexible. In short, the two overriding assumptions are that no direct resupply other than the basic load is possible, and the combat scenario is such that the amount of basic load logistics support must remain constant for each group of reinforcements.

This model uses a modification of the Lanchester square law discussed earlier to incorporate logistics considerations into the attrition dynamics of the Blue and Red force sizes. The logistics considerations are not specifically defined; rather they are represented as a straight percentage input.

Consider a scenario where there are several landing craft coming ashore at the rate of one per selected input time increment. The force commander and his staff know that in addition to the combatants, each landing craft must also carry the supplies necessary to sustain those combatants for the duration of the conflict ashore. Also each landing craft has a fixed maximum number of troops or combination of troops and amount of supplies that it can carry. Hence, in order to maintain a certain combat effectiveness against the enemy, the force commander must adequately balance the number of combatants with the percentage of the landing craft that will be utilized for supplies to support the force. The model and computer program presented here will allow the force commander and his staff to quickly predict the outcome in several such scenarios.

B. ILLUSTRATION

Throughout the illustration, the reader will encounter model parameters that may be unfamiliar. These parameters are defined and explained in the next section. For demonstrational purposes only, assume that the Blue force landing plan calls for one landing craft to land at time 0 and every ten minutes for thirty minutes thereafter. The maximum capacity for each landing craft is assumed to be 150 troops. The Blue force commander and his staff have decided to analyze a scenario in which it is possible to maximize landing craft capabilities, but 20% of each landing craft needs to be utilized for logistics purposes. As a result, the commander estimates that the combat

effectiveness of each entity in the Blue landing craft against each entity of the Red force is .8 Red casualties/Blue entity per minute. Through intelligence, the Blue force commander knows that the Red force will be present on the battlefield at time 0 with a strength of 500 troops. 10% of these troops are logistics and other support personnel and will not participate in the fighting. As a result, the commander estimates that the combat effectiveness of each entity of the Red force against each entity of the Blue force is .6 Blue casualties/Red entity per minute. The Blue force commander wants to estimate how the battle might progress, in 10 minute increments.

Figure 2.1 shows the output for the above scenario, utilizing the computer program for this first model. Note that the output is simple and provides an easy interpretation of the solution.

The results show through square law attrition that the Blue force was quickly annihilated while the Red force survived sustaining relatively light casualties.

TIME MIN.	BLUE STRENGTH	BLUE DEAD	RED STRENGTH	RED DEAD
0	120	0	450	0
10	119	120	428	21
20	119	240	405	44
30	119	360	380	69
40	0	480	354	95

Figure 2.1 Output of Illustration for the First Model.

Suppose the Blue force commander finds these results very unsettling, and his staff has indicated that by changing certain battle parameters an increase in the attrition rate coefficient against the Red force can be achieved such that the Blue force combat effectiveness can be increased three fold to 2.4. Figure 2.2 shows the results of the modified scenario. The Blue force was victorious but sustained extremely heavy casualties. Note that in both illustrations the time to annihilate one of the forces was fairly short. This was due to the high combat effectiveness inputs. Had these values been cut in half, the output would have been extended by several ten minute increments.

C. THE MODEL

The heart of this model is the structure of the modified differential equations used in the Lanchester square law attrition process. The square law has been expanded

TIME MIN.	BLUE STRENGTH	BLUE DEAD	RED STRENGTH	RED DEAD
0	120	0	450	0
10	119	120	380	69
20	119	240	295	154
30	119	360	173	276
40	82	397	0	450

Figure 2.2 Output of Modified Illustration for the First Model.

so that the rate at which the Blue force is being attrited, as a function of time, is equal to the size of the Red force at time "t" multiplied by a constant plus the number of Blue reinforcements added at time "t" multiplied by a constant. Suppose the same is true for the Red force. The attrition rate contribution is given by:

$$dB(t)/dt = -a(t)R(t)$$
$$dR(t)/dt = -b(t)B(t) \qquad \text{(eqn 2.1)}$$

At specific points in time, a number of reinforcements equal to cBa(t) and eRa(t) are added to the Blue and Red forces respectively. Ba(t) and Ra(t) are the maximum number of replacements possible at time "t". "c" and "e" are the portions of Ba(t) and Ra(t) respectively which will be added as replacements at time "t". The terms (1-c) and (1-e) are refered to as the logistics percentages. [Ref. 8: pp. 464-481]

Consider the scenario in which there is one Blue force landing craft loaded to full capacity with combat-ready troops on their way into battle. This fighting force has a certain combat effectiveness against a given Red enemy force which varies depending on the type and size of the enemy force. Suppose 20% of those combat troops are removed and replaced with essential combat supplies (ammunition, water, medical supplies, etc.) needed to sustain the battle. Even though the combat supplies are critical to the outcome of the battle, they themselves cannot do any direct fighting. It follows that the 20% of the Blue force combat troops that were removed from that landing craft to make room for the supplies would degrade the fighting force size by 20%. Hence, there is 80% of the original combat strength remaining in that fighting force. Further suppose that the landing craft with the combat troops and supplies on board are the Blue reinforcements added at time "t" as previously described. Then .8 is the replacement rate coefficient "c" described above. The same reasoning holds for the

Red force which explains the replacement rate coefficient "e" described above. The replacement rate coefficients represent the place in the model where logistics considerations impact on the reinforcements.

The Lanchester attrition rate coefficients a(t) and b(t) are a combination of the original effectiveness parameters and a built-in sensitivity analysis multiplication factor which is explained later. The user should be aware that there may be a dependent relationship between the attrition rate coefficient and the replacement rate coefficient. In general, the more correct logistics support that is provided, the higher the combat effectiveness of that force becomes. However, due to the increased amount of space occupied by the increased amount of supply support in this model, the replacement rate coefficient will have to decrease thus reducing the number of reinforcements. Hence, there exists an inherent trade-off between the attrition rate coefficients and the replacement rate coefficients. This is the purpose for separating the replacement rate coefficients from the reinforcement term in Equation 2.1. The values used as inputs for the model parameters in Equation 2.1 to obtain the output in Figure 2.1 are as follows: B(0) and R(0) are 150 and 500 respectively; Ba(10), Ba(20), and Ba(30) are 150, 150, and 150 respectively; a(t) and b(t) are constant at .8 and .6 respectively; and "c" and "e" are .8 and .9 respectively.

As mentioned previously, this model is flexible, but there are several strong assumptions. The following paragraphs are descriptions and explanations of model assumptions and parameters.

This model is a time step model where the step time increments used to update a run of the computer program for this model are preset to one second. The time step need not be one second. It can be any value determined through experience or experimentation to be applicable to user specific needs as it depends on the numerical solution accuracy required. The purpose is to attempt to reduce the amount of error for each iteration of the model. One iteration is defined to be one pass through the main loop of the main computer program using one second of simulated time which is the step time increment. In general, the shorter the time increments the more accurate the solution will be. B′(t) and R′(t) are slopes of the functions B and R at a particular point in time "t". The longer the time increments, the longer the line segment with that slope has to be used as an approximation to the function until the slope is updated. If the time increment is too long and the combat scenario is such that radical changes in attrition are possible, then the output may not be accurate. In our programs, these

time increments are the same for both the Blue and Red force sizes. If the Blue force is engaged in combat with the Red force for a given length of time, it is assumed that the Red force is engaged in combat with the Blue force for same amount of time.

The input time increment used for replacement to input new troops into the scenario can be of any duration, dimensioned in minutes. However, once the time increment is selected, it will remain the same throughout the model and in the program. The user can define the time increment to be a partial duration of the battle or, it may be interpreted as the length of time the combat essential supplies will last, or some fraction thereof.

The combat effectiveness inputs (attrition rate coefficients) represent the actual combat effectiveness of one entity of the Blue or Red force against one entity of the other force during each step time increment. The combat effectiveness inputs need not be the same for the Blue and Red forces, and they are taken as input for each input time increment by the input program. These combat effectiveness inputs can be actual representations of true scenarios from historical experiences, modifications of these true scenarios, or judgement calls on the part of the commander or user. The latter requires considerable experience in order to obtain reasonable results. However, it is also one point where cause and effect flexibility is built in to this and other models. Combat effectiveness can be composed of many different factors, and they may change over time, or from one scenario to the next. The assignment of combat effectiveness inputs in this model allows the analyst to represent changes so as to be applicable to many different possible situations. This flexibility is further enhanced by the built-in sensitivity analysis characteristic which will be discussed later in this chapter. The sensitivity analysis capability is what was used to quickly change the data of the illustration to give the results in Figure 2.2.

The logistics percentage inputs entered with the main program are numbers between zero and one. They represent the percentage (in decimal form) of each incoming combat load for which space is occupied by logistics considerations or combat supplies. The logistics percentage inputs need not be the same for the Blue and Red forces, but they are assumed to remain the same for every input time increment throughout the duration of the simulated battle. These percentages can have many different interpretations. As long as the other assumptions of this model are met, through these interpretations the model can be adapted to meet differing scenarios. For example, the logistics percentages could be actual combat essential

supplies for the immediate battle, supplies to be brought into the combat area but stored and not used, personnel that would be used in a non-combat support role, etc. The program is designed so that the logistics percentages can also be easily changed via the built-in sensitivity analysis characteristic without rerunning the input program.

This basic model does not take into consideration running out of supplies nor does it directly consider resupply efforts. As suggested earlier, the input time increment could be based on the estimated amount of time the initial basic load of combat supplies brought in with each incoming replacement or reinforcement will last. The supplies brought in on each incoming load per input time increment could be considered an indirect resupply effort. If the supplies are not used by the troops that they came in with, then the supplies are assumed to be stored somewhere in the battle area. In any case, the combat supplies are intended to occupy space that would normally be filled by combatants thus decreasing overall combat firepower.

The user may want to rerun the main program changing certain critical parameters without having to rerun the input program. The main program is designed with a sensitivity analysis characteristic such that after every run it will ask the user if another run is desired. A "yes" reply will take the user back to place in the program where the user is prompted for "force multipliers" and "logistics percentages". For example, the Blue force attrition rate coefficient $a(t)$ in Equation 2.1 is composed of the combat effectiveness multiplied by the Blue force multiplier. The multiplier is a number greater than zero which directly multiplies the combat effectiveness of the combatants in the Blue force at time "t" by that number. It has a default value of one, and it plays no part in the calculations unless the user changes the default value. The net effect is that a user can see what happens to $dR(t)/dt$ when the combat effectiveness is changed without rerunning the input program. The logistics percentages are simply changed by replacing the current percentage with a new value. These capabilities form the sensitivity analysis characteristic for this model.

As previously discussed this model does not fit any one particular type of force or battle scenario. It is general and flexible in that it provides a rough model for a great number of different situations. There are two additional points that should be considered by the user when using this model. They are discussed below.

Each input time increment considers one element of a force. This element can be almost anything. It can represent small units such as a squad in a helicopter, a company in a landing craft, or even large groups of helicopters or landing craft, as long

as the percentage of logistics is the same for each element. The element can also be interpreted as a force by itself without a mode of delivery. The logistics percentage might represent the portion of the combat force that must stay back to handle or control the supplies, so it would not be able to participate in the actual battle.

By making the percent logistics equal to zero, logistics can be removed from the model. This would essentially revert this model back to a basic force on force attrition square law model without logistics considerations. This case will not be discussed further in this thesis.

D. THE COMPUTER PROGRAM AND ITS USE

The computer programs mentioned earlier in this chapter are presented in detail at the end of this section. They are designed to be interactive so as to reduce the difficulty with inputing data and running the programs. The following discussion is a user's manual which explains how to use the programs and what to expect from them:

1. Load the input program. Note that the input program must be run twice, one time for each force.
2. When the run command is executed the reply will be the prompt for "name of force=?". Type in the name of the force and return.
3. The user will then be prompted only once for "time increment=?". Enter the duration of time in minutes for each input time increment without the units of time and return. Do not input "minutes" with the numbers.
4. The reply will be the statement "enter force size (end with -1)", and on the next line the prompt will be "time= 0?" The user should then enter the number of combatants B(0) or R(0) (greater than or equal to 0) desired for the first time increment and return.
5. The reply will be "combat effectiveness=?". The user should then enter a number greater than or equal to zero which represents the combat effectiveness of the size force just previously entered for that input time increment and return.
6. The program is designed to continue to prompt the user with "time= _?" for the force size and combat effectiveness for each consecutive input time increment until the user enters "-1" for force size and returns. The user can then enter any number for the last combat effectiveness input and the data will be saved in a file under the name of the unit entered earlier.

7. The user must run the entire input program a second time for the opposing force. If the user desires to use the identical data for both forces, then only run the input program once and use the same unit name when prompted by the main program for the name of the Blue and Red forces. The user can utilize the sensitivity analysis characteristic of the program to introduce differences between the Blue and Red forces.
8. Load the main program.
9. When the run command is executed, the reply will be a display of a list of the available input files produced by the input program and an immediate prompt for the "name of the Blue force=?". Enter the name of a file that applies to this program from those just displayed and return. The reply will be a prompt for the "name of the Red force=?". Enter the name of a file that applies to this program from those just displayed and return.
10. The reply will be that the "current Blue multiplier= 1", and a prompt for the user to enter a number for "new value=?". Input the desired multiplier greater than zero and return. The reply will be that the "current Red multiplier= 1", and a prompt for the user to enter a number for "new value=?". Input the desired multiplier greater than zero and return. It is likely that for the first run of the program the user will allow both force multipliers to remain "1". Either enter the value of "1" or just return which will default to the current value displayed in this case "1".
11. The reply will be that the "current Blue logistics percentage= 0", and a prompt for the user to enter a number for "new value=?". Input the desired percentage in decimal form between zero and one (inclusive) and return. The reply will be that the "current Red logistics percentage= 0", and a prompt for the user to enter a number for "new value=?". Input the desired percentage in decimal form between zero and one (inclusive) and return.
12. The reply will be a display of the results by increasing time increments in 5 columns labeled "TIME MIN.", "BLUE STRENGTH", "BLUE DEAD", "RED STRENGTH", and "RED DEAD". The program run will stop when the first force strength column reaches zero. That force has been annihilated.
13. The final reply will be a prompt for the user to answer the question "another run?" Entering "no" with a return will end the program run. Entering "yes" with a return will cause a return to where new inputs are allowed for the Blue

and Red multiplication factors and logistics percentages. Changing these numbers and continuing with the program allows the user to conduct a sensitivity analysis.

For convenience, a list of variables used in the main program is provided in Table 2. Table 3 displays the computer code in the BASIC language for the data input program. The purpose for this program is to set up, appropriately structure, and save data files independently so they can be used by the main program. Table 4 displays the main computer program for this model. Using the list of variables in Table 2, the main program is easy to follow, and the lines of code are modularized for easy modification to suit user specific applications.

TABLE 2

LIST OF VARIABLES FOR THE FIRST MODEL MAIN PROGRAM

```
B$  - Character variable name for the Blue force
R$  - Character variable name for the Red force
Y$  - Character variable response to "another run?"
B   - Array for Blue strength input
C   - Red combat effectiveness multiplier
I   - Counter
J   - Main loop control variable (1 second steps)
K   - Blue combat effectiveness multiplier
R   - Array for Red strength input
T   - Input time increment
BC  - Integer value of TBxB1
BF  - B=-1 prevention variable for Blue
BT  - Integer value of B1
PB  - Percent Blue Logistics
PR  - Percent Red logistics
RC  - Integer value of TR-R1
RF  - R=-1 prevention variable for Red
RT  - Integer value of R1
TB  - Total Blue count entering the battle scenario
TR  - Total Red count entering the battle scenario
B1  - Remaining Blue for each iteration
C1  - Red multiplier input
C2  - Array for Red combat effectiveness input
C3  - Temporary Storage for C2
K1  - Blue multiplier input
K2  - Array for Blue combat effectiveness input
K3  - Temporary storage for K2
R1  - Remaining Red for each iteration
PB1 - Percent Blue logistics input
PR1 - Percent Red logistics input
TB1 - Temporary storage for B1
TR1 - Temporary storage for R1
```

TABLE 3

INPUT PROGRAM FOR THE FIRST MODEL

```
10 INPUT "name of FORCE=",A$
20 INPUT "time increment=",T
30 OPEN "b:"+A$ FOR OUTPUT AS #1
40 PRINT #1,T
50 PRINT "enter FORCE SIZE (end with -1)
60 FOR I=0 TO 99
70 PRINT "time=";I*T;
80 INPUT A
90 IF A=0 THEN 120
100 INPUT "COMBAT EFFECTIVENESS=";R1
110 IF R1<>0 THEN R=R1
120 PRINT #1,A,R/(T*60)
130 IF A<0 THEN 150
140 NEXT I
150 CLOSE
160 END
```

TABLE 4

MAIN PROGRAM FOR THE FIRST MODEL

```
10 FILES "b:
20 '
30 '*****ARRAY DIMENSIONS*****
40 '
50 DIM B(100),R(100)
60 DIM K2(100),C2(100)
70 '
80 '*****FORCE AND FILE IDENTIFICATIONS*****
90 '
100 INPUT "name of the BLUE FORCE=";B$
110 INPUT "name of the RED FORCE="; R$
120 '
130 '*****READS BLUE INPUT FROM INPUT PROGRAM*****
140 '
150 OPEN "b:"+B$ FOR INPUT AS #1
160 INPUT #1,T
170 PRINT "BLUE INPUT"
180 FOR I=0 TO 100
190     INPUT #1,B(I),K2(I)
200     IF B(I)<0 THEN 230
210     PRINT I*T,B(I),K2(I)
220 NEXT I
230 CLOSE 1
240 '
250 '*****READS RED INPUT FROM INPUT PROGRAM*****
260 '
270 OPEN "b:"+R$ FOR INPUT AS #1
280 INPUT #1,T
290 PRINT "RED INPUT"
300 FOR I=0 TO 100
310     INPUT #1,R(I),C2(I)
320     IF R(I)<0 THEN 350
330     PRINT I*T,R(I),C2(I)
340 NEXT I
350 CLOSE 1
360 '
370 '*****INITIALIZATIONS*****
380 '
390 C=1:K=1
400 PB=0:PR=0
410 TR=0:TB=0
420 BF=1: RF=1
430 '
440 '****MULTIPLICATION FACTORS FOR SENSITIVITY ANALYSIS****
450 '
460 PRINT "current BLUE MULTIPLIER=";K
470 INPUT "new value=";K1
480 IF K1<>0 THEN K=K1
490 PRINT "current RED MULTIPLIER=";C
500 INPUT "new value=";C1
510 IF C1<>0 THEN C=C1
520 '
530 '*****LOGISTICS FACTORS INPUTS, AND CHECKS*****
540 '
550 PRINT "current BLUE LOGISTICS PERCENTAGE=";PB
560 INPUT "new value=";PB1
570 IF PB1<>0 THEN PB=PB1
```

TABLE 4

MAIN PROGRAM FOR THE FIRST MODEL (CONT'D.)

```
580 PRINT "current RED LOGISTICS PERCENTAGE=";PR
590 INPUT "new value=";PR1
600 IF PR1<>0 THEN PR=PR1
610 R1=R(0)*(1-PR):B1=B(0)*(1-PB)
620 TB=B1:TR=R1
630 K3=K2(0):C3=C2(0)
640 I=0
650 '
660 '*****SETS UP OUTPUT HEADER*****
670 '
680 PRINT :PRINT :PRINT
690 PRINT "TIME","BLUE","BLUE","RED","RED"
700 PRINT "MIN.","STRENGTH","DEAD","STRENGTH","DEAD"
710 PRINT
720 '
730 '*****MAIN PROGRAM LOOP*****
740 '
750 FOR J=0 TO 36000!
760    TB1=B1:TR1=R1
770    IF J=0 THEN 1070
780    X$=INKEY$:IF X$<>"" THEN 1120
790    IF J=I*T*60 THEN 880
800    R1=TR1-TB1*K*K3
810    B1=TB1-TR1*C*C3
820    IF B1<0 THEN B1=0
830    IF R1<0 THEN R1=0
840    GOTO 1110
850    '
860    '***BLUE AND RED LOGIC SWITCHES***
870    '
880    IF R(I)<0 THEN RF=0
890    IF RF=1 THEN C3=C2(I)
900    IF B(I)<0 THEN BF=0
910    IF BF=1 THEN K3=K2(I)
920    '
930    '***LANCHESTER EQUATIONS AND CALCULATIONS***
940    '
950    R1=TR1+R(I)*RF*(1-PR)-TB1*K*K3
960    IF R1<0 THEN R1=0
970    B1=TB1+B(I)*BF*(1-PB)-TR1*C*C3
980    IF B1<0 THEN B1=0
990    '
1000    '***TOTAL BLUE AND RED COUNTERS***
1010    '
1020    TR=TR+RF*R(I)*(1-PR)
1030    TB=TB+BF*B(I)*(1-PB)
1040    '
1050    '***PREPARES AND PRINTS OUTPUT***
1060    '
1070    BT=INT(B1):RT=INT(R1):BC=INT(TB-B1):RC=INT(TR-R1)
1080    PRINT T*I,BT,BC,RT,RC
1090    IF (INT(R1)=0 OR INT(B1)=0) AND RF+BF=0 THEN 1120
1100    I=I+1
1110 NEXT J
1120 INPUT "another run?"; Y$
1130 IF Y$="y" OR Y$="Y" THEN 410
1140 END
```

III. MODELING WITH VARYING LOGISTICS PERCENTAGES

A. INTRODUCTION

This model and computer program is the second of the three to be presented in this thesis. It is a direct result of expanding the first model in Chapter 2 to the next level. Although these models and programs are similar, one purpose for presenting this model and program is to show the reader the ease with which they can be modified to produce other models and programs to suit user specific needs and differing scenarios. Another purpose is to provide the reader with a second user ready model before discussing the third model, which may require modification prior to use, and the intermediary steps needed to develop it.

Consider a scenario where there are several landing craft coming ashore one per selected time increment. Recall in the illustration of the first model, the force commander and his staff determined what percentage logistics the first and hence the entities in all the landing craft would have. Suppose the staff now recommends that due to the changing combat environment ashore, it is essential to have a logistics build-up ashore initially and a continuous tapering off or increase of incoming supplies after the first few landing craft. This scenario can be examined by the model and computer program discussed in this chapter. In short, the second model provides the ability to vary not only the combat effectiveness as in the first model but also the logistics percentages as a function of time or per selected incoming loads.

B. ILLUSTRATION

Throughout the illustration, the reader will encounter model parameters that may be unfamiliar. These parameters are defined and explained in the next section. For illustrational purposes, assume that the Blue force division G-4 wants to demonstrate the importance of logistics in the combat scenario as discussed in Chapter 1. Let the Blue force have available four landing craft with maximum capacities of 200, 250, 300, and 350 combat troops that will land at time 0, 10, 20, and 30 respectively. Assume that the combat scenario ashore requires a small amount of combat essential supplies at first, with an increasing need during each future input time increment. Hence, a logistics percentage of 10% will be allowed for the first landing craft, 15%, 20%, and 25% respectively for the remaining three. Due to the increased amount of the correct

combat essential supplies available, the combat effectiveness inputs will increase starting at .5 for the first set of combatants in the first landing craft, .6, .7 and .8 respectively for the remaining three. This would be indicative of a smaller fighting force that had an effective and efficient combat logistics support system. Now assume the larger Red force can reinforce six times with maximum numbers of 250, 250, 250, 300, 300, and 300 troops respectively that will be available in that order starting with the first one at time 0 and at 10 minute intervals up to and including time 50. Further assume the Red force uses a constant logistics percentage of 15% for each set of combatants entering the scenario. Also the Red force has a history of somewhat ineffective and inefficient combat logistics support capabilities, so the combat effectiveness inputs are assumed to remain constant at .4 for each set of combatants landing per time increment. In summary this particular scenario puts a numerically inferior Blue force having a stronger increasing combat effectiveness due to superior combat logistics capability against a numerically superior Red force having a weaker overall combat effectiveness due to an inferior combat logistics capability. It should be noted that the input time increments do not have to be restricted to 10 minute intervals nor do they have to be the same for the Blue and Red forces. For example, the input time increments might be 10 minutes for the Blue force and 25 minutes for the Red force. In this case, the best approach would be to take the least common divisor of the input time increments for both forces, use it for both forces, and simply input zeros as inputs for the inbetween time intervals. In the above example, the least common denominator is 5 minutes. Hence, there would be one inbetween time interval for the Blue force and four for the Red force for each point in time when actual reinforcement inputs would be required.

Figure 3.1 shows the main program output for the above scenario. The output shows that even though the Blue force lost nearly 50% of its total strength, it annihilated the numerically superior Red force at time 60. This illustration is certainly not intended to prove anything in general about logistics support capability in the combat scenario, but the reader can see that these models and their respective computer programs can be used to examine such effects.

C. THE MODEL

The second model uses a modification of the Lanchester square law as did the first model. This model incorporates varying logistics percentages as a function of time

TIME MIN.	BLUE STRENGTH	BLUE DEAD	RED STRENGTH	RED DEAD
0	180	0	212	0
10	322	69	353	71
20	455	177	407	229
30	574	282	387	505
40	505	352	254	893
50	471	385	254	1148
60	436	421	0	1402

Figure 3.1 Output of Illustration for the Second Model.

into the attrition dynamics of the Blue and Red forces. The logistics considerations are no longer straight percentages, and as before the combat effectiveness inputs are not required to be constant; rather they are input initially for each selected input time increment.

The mathematical description of this model is similar to that of the first model except that the attrition rate coefficients and the replacement rate coefficients may now vary with the input time increment. As before, the attrition rate contribution is given by:

$$dB(t)/dt = -a(t)R(t)$$
$$dR(t)/dt = -b(t)B(t) \qquad \text{(eqn 3.1)}$$

At specific points in time in this model, a number of reinforcements equal to c(t)Ba(t) and e(t)Ra(t) are added to the Blue and Red forces respectively. The terms outlined above and in Equation 3.1 have the same interpretation as those in the first model except that the replacement rate coefficients can now vary with time and are represented as c(t) and e(t). [Ref. 8: pp. 464-481] In the illustration provided earlier, the Blue force commander determined that combat effectivenesses of .5, .6, .7, and .8 would be used. These differing combat effectivenesses represent the a(t) term in Equation 3.1. The same reasoning can be used to explain b(t) for the Red force. The attrition rate coefficients a(t) and b(t) represent the place in the model where the varying combat effectiveness inputs are taken into account. Also, the Blue force commander decided to start with 10% logistics in the first landing craft, 15% in the second, 20% in the third, and 25% in the last. These differing logistics percentages

represent the (1-c(t)) expression which is similar to that in the first model. The same reasoning can be used to explain how e(t) is used for the Red force. The replacement rate coefficients c(t) and e(t) represent the place in the model where the varying logistics considerations are taken into account.

The description of assumptions and parameters provided in the first model are all applicable to this model with the exception of the logistics percentage. The definition of logistics percentage is the same, but it is no longer a single input. In this model a logistics percentage must be entered for each input time increment or incoming load. As a result, the sensitivity analysis characteristic for the logistics percentage is no longer available for this model as it was in the first model. In order to change logistics percentages, all new data must be input to rerun the main computer program for this model. If all the individual logistics percentages are input with the same value, the results obtained from using this model, of course, will be identical to the results obtained using the first model with a constant logistics percentage input. The values used as inputs for the model parameters above to obtain the output in Figure 3.1 are as follows: B(0) and R(0) are 200 and 250 respectively; Ba(10), Ba(20), and Ba(30) are 250, 300, and 350 respectively; Ra(10), Ra(20), Ra(30), Ra(40), and Ra(50) are 250, 250, 300, 300, and 300 respectively; a(0), a(10), a(20), and a(30) are .5, .6, .7, and .8 respectively; b(t) is constant at .4; c(0), c(10), c(20), and c(30) are .9, .85, .8, and .75 respectively; and e(t) is constant at .85.

D. THE COMPUTER PROGRAM AND ITS USE

The detailed input program and main program are very similar to the programs discussed in Chapter 2, and the user guidance differs only in two areas:

1. With respect to the input program, after the user enters the "combat effectiveness" for each time increment, the reply will be a prompt for the user to enter a value for "logistics percentage=?". Enter the desired logistics percentage between zero and one for that time increment and return. This sequence will be repeated until the user enters "-1" for force size which signifies the end of input for that force. At this point, the last entries for combat effectiveness and logistics percentage can be any value as they are meaningless and only serve to complete the input of this force. The user will experience the same input sequence when entering data for the opposing force.

2. With respect to the main program, after the user has entered the desired values for the Blue multiplier and Red multiplier, the reply will be to go directly to displaying the results as described in Chapter 2. The logistics percentage interface present in the first model has been deleted from the main program and moved to the input program.

The program structure and the actual code for the first model and those for this second model are very similar. Nearly all the variables are the same. The only additional variables in the second model are LB and LR which are percent Blue logistics and percent Red logistics respectively. The only variables deleted were PB1 and PR1. PB and PR are still used in the second model, but their roles have been changed to that of temporary holders or dummy variables for LB and LR respectively. The dummy variables PB and PR were used as temporary holders so the coding for the actual Lanchester equation calculations would be the same for both the first and second models. This provides some insight into the mechanics of how the computer programs were designed and how the user might modify them to suit differing scenarios.

Table 5 shows the BASIC language code for the input program of this model. Note the addition of the logistics percentage consideration which was not part of the input program for the first model (See Table 3). Table 6 shows the BASIC language code for the main program of this model. Note the deletion of the logistics percentage consideration which was part of the main program for the first model (See Table 4). Moving the logistics percentage consideration from the main program to the input program in this model was done to allow the logistics considerations to vary with time. The programs were written so that code for entire concepts were grouped together. This allows changes in the programs to be incorporated easily.

TABLE 5

INPUT PROGRAM FOR THE SECOND MODEL

```
10 INPUT "name of FORCE=",A$
20 INPUT "time increment=",T
30 OPEN "b:"+A$ FOR OUTPUT AS #1
40 PRINT #1,T
50 PRINT "enter FORCE SIZE (end with -1)
60 FOR I=0 TO 99
70 PRINT "time=";I*T;
80 INPUT A
90 IF A=0 THEN 140
100 INPUT "COMBAT EFFECTIVENESS=";R1
110 IF R1<>0 THEN R=R1
120 INPUT "LOGISTICS PERCENTAGE=";L1
130 IF L1<>0 THEN L=L1
140 PRINT #1,A,R/(T*60),L
150 IF A<0 THEN 170
160 NEXT I
170 CLOSE
```

TABLE 6

MAIN PROGRAM FOR THE SECOND MODEL

```
10 FILES "b:
20 '
30 '*****ARRAY DIMENSIONS*****
40 '
50 DIM B(100),R(100)
60 DIM K2(100),C2(100)
70 DIM LB(100),LR(100)
80 '
90 '*****FORCE AND FILE IDENTIFICATIONS*****
100 '
110 INPUT "name of the BLUE FORCE=";B$
120 INPUT "name of the RED FORCE="; R$
130 '
140 '*****READS BLUE INPUT FROM INPUT PROGRAM*****
150 '
160 OPEN "b:"+B$ FOR INPUT AS #1
170 INPUT #1,T
180 PRINT "BLUE INPUT"
190 FOR I=0 TO 100
200     INPUT #1,B(I),K2(I),LB(I)
210     IF B(I)<0 THEN 240
220     PRINT I*T,B(I),K2(I),LB(I)
230 NEXT I
240 CLOSE 1
250 '
260 '*****READS RED INPUT FROM INPUT PROGRAM*****
270 '
280 OPEN "b:"+R$ FOR INPUT AS #1
290 INPUT #1,T
300 PRINT "RED INPUT"
310 FOR I=0 TO 100
320     INPUT #1,R(I),C2(I),LR(I)
330     IF R(I)<0 THEN 360
340     PRINT I*T,R(I),C2(I),LR(I)
350 NEXT I
360 CLOSE 1
370 '
380 '*****INITIALIZATIONS*****
390 '
400 I=0
410 C=1:K=1
420 TR=0:TB=0
430 PB=0:PR=0
440 BF=1:  RF=1
450 R1=R(0)*(1-LR(0)):B1=B(0)*(1-LB(0))
460 TB=B1:TR=R1
470 K3=K2(0):C3=C2(0)
480 '
490 '****MULTIPLICATION FACTORS FOR SENSITIVITY ANALYSIS****
500 '
510 PRINT "current BLUE MULTIPLIER=";K
520 INPUT "new value=";K1
530 IF K1<>0 THEN K=K1
540 PRINT "current RED MULTIPLIER=";C
550 INPUT "new value=";C1
560 IF C1<>0 THEN C=C1
570 '
```

TABLE 6

MAIN PROGRAM FOR THE SECOND MODEL (CONT'D.)

```
580 '*****SETS UP HEADER OUTPUT*****
590 '
600 PRINT :PRINT :PRINT
610 PRINT "TIME","BLUE","BLUE","RED","RED"
620 PRINT "MIN.","STRENGTH","DEAD","STRENGTH","DEAD"
630 PRINT
640 '
650 '*****MAIN PROGRAM LOOP*****
660 '
670 FOR J=0 TO 36000!
680    TB1=B1:TR1=R1
690    IF J=0 THEN 990
700    X$=INKEY$:IF X$<>"" THEN 1040
710    IF J=I*T*60 THEN 800
720    R1=TR1-TB1*K*K3
730    B1=TB1-TR1*C*C3
740    IF B1<0 THEN B1=0
750    IF R1<0 THEN R1=0
760    GOTO 1030
770    '
780    '***BLUE AND RED LOGIC SWITCHES***
790    '
800    IF R(I)<0 THEN RF=0
810    IF RF=1 THEN C3=C2(I):PR=LR(I)
820    IF B(I)<0 THEN BF=0
830    IF BF=1 THEN K3=K2(I):PB=LB(I)
840    '
850    '***LANCHESTER EQUATIONS AND CALCULATIONS***
860    '
870    R1=TR1+R(I)*RF*(1-PR)-TB1*K*K3
880    IF R1<0 THEN R1=0
890    B1=TB1+B(I)*BF*(1-PB)-TR1*C*C3
900    IF B1<0 THEN B1=0
910    '
920    '***TOTAL BLUE AND RED COUNTERS***
930    '
940    TR=TR+RF*R(I)*(1-PR)
950    TB=TB+BF*B(I)*(1-PB)
960    '
970    '***PREPARES AND PRINTS OUTPUT***
980    '
990    BT=INT(B1):RT=INT(R1):BC=INT(TB-B1):RC=INT(TR-R1)
1000    PRINT T*I,BT,BC,RT,RC
1010    IF (INT(R1)=0 OR INT(B1)=0) AND RF+BF=0 THEN 1040
1020    I=I+1
1030 NEXT J
1040 INPUT "another run?"; Y$
1050 IF Y$="y" OR Y$="Y" THEN 420
1060 END
```

IV. MODELING WITH RESUPPLY CONSIDERATIONS

A. INTRODUCTION

This model and computer program is the third and last of the three to be presented in this thesis. It is a heterogeneous Lanchester formulation, and it represents a three level expansion of the previous model in Chapter 3. Two intermediary steps will be briefly addressed to reveal the logical progression of steps used to develop this third model and program. The reader can utilize similar steps to develop other models and programs to suit specific needs and differing scenarios.

In the previous two models, the force on force attrition process was limited to one kind of combatant. The respective illustrations used troops to demonstrate the capabilities of the models and associated programs. In more realistic situations there is likely to be more than just troops involved in an engagement between the Blue and Red forces. In addition to troops there may be tanks, artillery, LAVs, amtracks, aircraft, or any number of different types of combat essential hardware. A logical expansion of the second model is to include the ability to involve such additional combat essential hardware items in the combat scenario, along with troops. This represents the first intermediary step towards the development of the third model. This can allow many different items to participate in an engagement. These different items will be referred to as TYPEs. For ease of development and demonstration, the TYPEs are restricted here to five different kinds.

With five different TYPEs involved in the model, a single force combat effectiveness in many scenarios may not be appropriate. For example, it is unlikely that the combat effectiveness of a single infantry-man against a tank is the same as that of a TOW against a tank. It is also unlikely that each TYPE of the Blue force is going to be engaged with each TYPE of the Red force for the same amount of time and vice versa. An expansion of the first intermediary step should be made to allow each Blue TYPE to have a different combat effectiveness and proportion of actual engagement time against each Red TYPE and vice versa. This represents the second intermediary step towards the development of this third model. For demonstrational purposes, we use three of the five TYPEs from the Blue force and Red force for the actual combatants (troops, tanks, artillery, TOWS, LAVs, etc.). Hence, TYPE 1,

TYPE 2, and TYPE 3 for each force will be used for this purpose. Of course, there is no conceptual limit on the number of TYPEs that could be incorporated into such a model.

The model allows multiple TYPEs for combatants, and corresponding combat effectivenesses and amounts of engagement time factors. It is desireable to include logistics considerations centered around resupply efforts. General logistics percentages are not appropriate in this case as the three TYPEs of combatants are likely to have different kinds of combat supply requirements. For example, LAVs would have a requirement for POL and troops would not; artillery units would have a requirement for artillery ammunition and troops would not. This necessitates direct input of various kinds of combat essential supplies. For both forces, TYPE 4 and TYPE 5 inputs are used in our model for for this purpose. The incorporation of this last step results in the final development of this third model. For our demonstration, we use two of the five TYPEs for combat essential supply considerations in order to support the three TYPEs of actual combatants. Once the techniques are understood, the five TYPEs could be expanded to any number of TYPEs which can easily be divided into any number of categories. As discussed later, this could be implemented by replicating lines of computer code and putting these in the correct location within the computer programs.

B. ILLUSTRATION

Throughout the illustration, the reader will encounter parameters that may be unfamiliar. These parameters are defined and explained in the next section. For illustration, the third model utilizes five TYPEs for modeling. Three are actually involved in the force on force attrition process, and two are utilized for supply support inputs to the model. The model has the ability to engage each of the three TYPEs of combatants of both the Blue and Red forces against each other through the use of independent and appropriate combat effectiveness inputs and proportion of engagement time factors. Resupply considerations are included through the use of the two combat supply TYPEs and an established resupply point. The TYPE 5 consideration has been further broken down into two subcategories to demonstrate how one can model a supply TYPE that has two separate uses such as two kinds of ammunition or POL.

An illustration will be provided with two purposes in mind. The first purpose is to demonstrate the output format for this model, as it differs considerably from that for the first two models. The second purpose is to demonstrate what happens when the Blue and Red forces are very nearly the same and to discuss a method of handling the output in such cases.

This paragraph will outline a scenario and identify the inputs necessary to run the computer program for this illustration. Consider a scenario in which the Blue force has labeled TYPE 1 as troops, TYPE 2 as artillery, TYPE 3 as LAV(AG)s, TYPE 4 as POL, and TYPE 5 as ammunition. Suppose the Red force TYPEs have the same identifications except for Red TYPE 3s which are BMPs. It is assumed that the terrain is marshy, and tanks would therefore not be used. LAV(AG)s and BMPs are suited for such terrain. It is further assumed that the battle is sufficiently short so that water and rations for the dúration of battle will be carried by the combatants and will not play as factors in this illustration. Diesel fuel is assumed to be the only POL. The LAV(AG)s and the BMPs will be the only users of POL, and they both are assumed to use fuel at a rate of 7 gallons per hour and have a fuel tank capacity of 71 gallons. Suppose two classes of ammunition are considered. One class that is applicable to troops (suppressive fire) and another that is applicable to artillery (indirect fire). The LAV(AG)s and BMPs will utilize both classes of ammunition. Suppose at time 0, Blue force counts of 1000 troops, 5 artillery guns, and 9 LAV(AG)s are present on the battle field with 100 gallons of fuel and 100,000 total rounds of ammunition available in addition to the initial load. This same mix of combatants and supplies will be added to the conflict for the Blue forces at times 10 and 20. We assume all excess supplies entering the scenario for each input time increment including those at time 0 go to a resupply point, and the combatants are resupplied from there. As the excess ammunition arrives at the supply point it is divided into groups for the combatant TYPEs that it is intended for: 60% is identified for the troops, 15% for artillery, and 25% for the LAV(AG)s. For each incoming load of supplies to the resupply point a predetermined amount of ammunition is sent directly from the resupply point to the combatants in the amount of 25,000 rounds for the troops, 400 rounds for the artillery pieces and 4000 rounds for the LAV(AG)s. The initial load of ammunition carried into the conflict is 120 rounds per troop, 30 rounds per artillery piece, and 1050 rounds per LAV(AG). The probability of kill for indirect fire ammunition is assumed to be .5 per round. Other than those outlined previously, there will be no additional combatants or

supplies added into the conflict. Suppose the combat effectiveness of the Blue Force troops against the Red force troops, artillery and BMPs is .6, 0, and 0 respectively. Assume the combat effectiveness of the Blue force artillery against the Red force troops, artillery, and BMPs is .6, .4, and .5 respectively. Suppose the combat effectiveness of the Blue force LAV(AG)s against the Red force troops, artillery, and BMPs is .6, .3, and .75 respectively. Assume the proportion of time the Blue force troops are expected to engage the Red force troops, artillery, and BMPs is .7, .1, and .2 respectively. Suppose the proportion of time the Blue force artillery is expected to engage the Red force troops, artillery and BMPs is .4, .4, and .2 respectively. Assume the proportion of time the Blue force LAV(AG)s are expected to engage the Red force troops, artillery, and BMPs is .3, .3, and .3 respectively. The factors for the TYPE 1 and TYPE 3 Blue and Red force rounds fired per unit per second is .1. Since the Red force is assumed to be nearly the same as the Blue force, we assume the total input for the Red force is identical to that of the Blue force. It is also assumed that there is adequate amounts of ammunition and fuel.

Figure 4.1 shows the output of the above illustration. It is a block style output, and the format is explained below. The first column of the output is labeled "SIDE" and it identifies the appropriate force. The first two entries in that column imply that the output of the first two rows pertain solely to the Blue force. The last two entries in that column imply that the output of the last two rows pertain solely to the Red force. The second column is labeled "TIME" and has a dual role for each force. The first entry in that column for each force is the current point in time of the scenario when this output was generated. Note how the time displayed is increasing by 10 minutes for each block of output. This is meant to imply that the first and third rows show the current active strength remaining for each combatant TYPE of the Blue and Red forces respectively at the time shown in the second column of those rows. The second and fourth rows in the second column labeled "dead" show the Blue and Red casualties respectively of each combatant TYPE for the same time period. For example, examine the third block of the output in Figure 4.1. The first two rows indicate that at time 20 the Blue force has 1217 troops, 6 artillery pieces, and 13 LAV(AG)s remaining in the conflict and 1783 troops, 9 artillery pieces, and 14 LAV(AG)s considered to be casualties or dead. Note that when the number remaining in the conflict and the number of casualties of each TYPE are added together, the result is 3000 troops, 15 artillery pieces, and 27 LAV(AG)s. These are the total quantities of each TYPE that participated in the conflict.

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	0	1000	5	9
blue	dead	0	0	0
red	0	1000	5	9
red	dead	0	0	0

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	10	1183	6	12
blue	dead	817	4	6
red	10	1183	6	12
red	dead	817	4	6

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	20	1217	6	13
blue	dead	1783	9	14
red	20	1217	6	13
red	dead	1783	9	14

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	30	223	1	5
blue	dead	2777	14	22
red	30	223	1	5
red	dead	2777	14	22

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	40	40	0	2
blue	dead	2960	15	25
red	40	40	0	2
red	dead	2960	15	25

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	50	7	0	1
blue	dead	2993	15	26
red	50	7	0	1
red	dead	2993	15	26

SIDE	TIME	TYPE1	TYPE2	TYPE3
blue	60	1	0	0
blue	dead	2999	15	27
red	60	1	0	0
red	dead	2999	15	27

Figure 4.1 Output of Illustration for the Third Model.

Observe the output for time 60. There is still one combatant remaining for each force. At time 70, the combat strengths for both the Blue and Red forces were reduced to zero. In order to reduce the output length and the program run time, the last block of output for time 70 is not shown, and a sensitivity analysis factor of four was used to run this illustration. Each ten minute block of output takes approximately 25 minutes to print.

The end result is no surprise. With the Blue and Red forces the same, they technically annihilated each other. However, there are two points of interest here. First, in a realistic scenario it is unlikely that two opposing forces would totally annihilate each other. It is more likely that a prudent commander would recognize that both forces are evenly matched long before total annihilation and would elect to terminate the engagement. This could be modeled by checking the output at each output time increment to see what percentage of total strength had been lost. Compare this with a predetermined value say 20% losses or 30% losses. If the percentage lost at any time is greater than the predetermined value, then terminate the engagement. This could be equally effective in a scenario where both the forces are not the same. Second, examine the last three blocks of the output in Figure 4.1 and compare them with the first four blocks of the output. Notice the trend that the number of remaining combatants killed in each of the later blocks is significantly less than those of the earlier blocks. When the two forces are the same, neither force maintains a progressive advantage. When this happens each force will be degraded by the same proportion, and the forces will reach total annihilation at the same time. As long as there exists some active portion of one combatant TYPE that is remaining, this cycle will continue. When a sensitivity analysis multiplication factor of 1 (the default) is used, there are several lines of output where there are two or one remaining combatant of one or more TYPEs before total annihilation. However, as long as there is sufficient ammunition and fuel, the force strengths will eventually reach zero. In this case and in the illustration above, the last several blocks of output serve no useful purpose. Calculating and printing them also greatly extends the run time and printout length of the program. If the illustration had been terminated after the loss of 50% of any one or a combination of combatant TYPEs, the run time and the printout length would have been substantially reduced. This shows why it is desireable in many cases to terminate the computer generated battle scenario once a predetermined percent loss of total strength has been incurred by one or both of the forces.

C. THE MODEL

The third model also uses a modification of the Lanchester square law. The mathematical representation is attained using the same procedures as discussed previously but with a slightly different end result. This model utilizes three TYPEs of combatants for both the Blue and Red forces. Hence, there must be an attrition term for each TYPE of the Blue force against each TYPE of Red force and vice versa. Mathematically this translates into the following:

$$dBi(t)/dt = -aR1(t) - cR2(t) - fR3(t) + hBia(t)$$
$$dRj(t)/dt = -bB1(t) - eB2(t) - gB3(t) + kRja(t) \qquad \text{(eqn 4.1)}$$

$dBi(t)/dt$ and $dRj(t)/dt$ where $i = 1,2,3$ and $j = 1,2,3$ are the attrition rates of Blue TYPE i and Red TYPE j combatants respectively as described in Chapter 1. For example, if $i = 1$ Equation 4.1 shows that the attrition rate of Blue TYPE 1 ($B1'$) is the sum of the strengths of each of the Red TYPE combatants, each multiplied by a constant, plus the number of Blue TYPE 1 replacements or reinforcements multiplied by a constant. The same explanation can be applied to any of the Blue TYPE i or Red TYPE j attrition rates. The constants "a", "b", "c", "e", "f", and "g" are the attrition rate coefficients for this model. These attrition rate coefficients are the same as those described earlier except that in this model there is one attrition rate coefficient for each force combatant TYPE, and the coefficients do not vary over time. However, as discussed below, these initial values are modified to account for factors such as ammunition, fuel level, etc. which vary over time. The variables "h" and "k" are the replacement rate coefficients in this model, and they are the same as described in the first model. Notice that this model can be expanded to as many combatant TYPEs as desired by having any number of terms on the right hand side of Equation 4.1. [Ref. 8: pp. 482-502]

In general, the attrition rate coefficients are calculated from a combat effectiveness term multiplied by a proportion of engagement time term multiplied by an ammunition factor term. The attrition rate coefficients differ only in the way that the ammunition factor terms are calculated. The ammunition factor term calculations vary by combatant TYPE. The following paragraphs are descriptions and explanations of these ammunition factor terms and other parameters, model assumptions, and modeling techniques of this third model.

The description of the time increment used to run and update the model as well as the time increments used to input new combatant TYPEs and supply support TYPEs are the same as those of the first model. As a reminder, the step time increment is preset to one second, and the input time increment can be any amount of time as long as it is dimensioned in minutes.

The initial combat effectiveness inputs are similar to those of the previous programs. However, in this model combat effectiveness is in terms of each entity of each TYPE of one force against each entity of each TYPE of the other force. For example, the combat effectiveness of one Blue force artillery piece against one Red force artillery piece might be .6. The numbers used as inputs for this parameter can be actual representations of true scenarios from history, modifications of these true scenarios, or judgement calls on the part of the commander or user. These initial combat effectiveness inputs form the heart of the attrition rate coefficients in Equation 4.1, and they are modified by several factors as mentioned previously.

The actual engagement time of Blue force or the Red force is no longer assumed to be 100% of the scenario time. It is unrealistic to assume that every combat TYPE of the Blue force and Red force will actually be fighting one or more TYPEs of the opposite force at all times. The proportion of time that each combatant TYPE of the Blue force is engaged with each combatant TYPE of the Red force is now left up to the user. These numbers may be hard to determine and are at best an expected value of engagement time based on the conditions surrounding the scenario and the judgement of the commander or user. The proportion of time inputs do not have to sum to one for each TYPE of each force. For example, the proportion of time that the Blue artillery could be engaged with the Red troops, artillery, and BMPs might be .3, .3, and .1 respectively. This would mean that the Blue artillery is being used 70% of the time as outlined above, and is idle 30% of the time. The proportion of time inputs form part of the attrition rate coefficients of Equation 4.1 as discussed previously.

There is no straight logistics percentage or a logistics percentage that varies with time in this model. All logistics considerations are essential combat supply support items that are specified as input. There are two ways to handle resupply considerations in this model, either by continuous force fed support or by requests for supplies that are stocked at a resupply point which arrive for use on a delayed time basis. Both of these conditions are considered in this model. The former is simulated in the main program by calculations prior to the Lanchester attrition calculations of the current

iteration, and the latter by calculations after the Lanchester attrition calculations of the current iteration. This is done to show a delay by a quantity of time equal to that of the initial input time increment. In this model, the Blue and Red force TYPE 2s (artillery) are modeled with the requests and time delay. The artillery ammunition resupply for both forces is assumed to be partially on an on call as needed basis with resupply arriving one preselected input time increment later. For example, if the Blue force artillery calls for an ammunition resupply at time 60 and the input time increment was 20 minutes, the Blue artillery would receive their ammunition resupply at time 80. However, additional artillery ammunition resupply for both forces is on a predetermined force fed basis. In this model, the Blue and Red force TYPE 1s and TYPE 3s are modeled as being without the delay. For both forces the troop ammunition, the LAV(AG) and BMP ammunition of both classes, and the LAV(AG) and BMP fuel is assumed to be resupplied on a predetermined force fed basis. It is further assumed that there will be no interference with the resupply efforts for both sides.

There are two input parameters that are directly related to the previous discussion. The first input parameter is the proportion of ammunition arriving that goes to the resupply point. This is the fraction of total newly incoming ammunition independent of ammunition classes that is predesignated for each combatant TYPE. For example, on any incoming load for the Blue force, suppose 40% of the ammunition were for the troops, 15% for the artillery pieces, and 15% for the LAV(AG)s. That would mean that 70% of this ammunition is intended for the three primary combatants to be stored as such at the resupply point, and 30% of this ammunition would be intended for another purpose that the user may determine. The proportions do not have to sum to one. If they do, it means that all the incoming ammunition is accounted for by combatant TYPE at the resupply point regardless of whether or not it is used. It is assumed that there is no interference with this process. The second input parameter is the amount of predetermined ammunition that is to be shipped to the combatants. This represents the predetermined amount of ammunition that will be force fed to each of these combatant TYPEs during a period of time that is equal to the initial input time increment as discussed previously. The amount of time between force fed resupplies does not have to be related to the initial input time increment. It can be any amount of time, but it was modeled in this way to demonstrate to the user how this could be done. The actual ammunition amounts can

be any value including zero. If zero is used, there will be no continuous force fed ammunition resupply for those combatant TYPEs. If a value is used that is greater than what is available at the resupply point, then that amount that is currently available at the resupply point will be sent. It is assumed that there will be no interference with this process. Both these parameters apply to the Blue and Red forces, but the input values do not have to be the same for either of the forces or their respective combatant TYPEs.

Another input parameter is that of the amount of ammunition independent of class that each entity of each combatant TYPE will carry into the engagement. For example, this would represent the initial number of rounds that a troop would carry with him into combat. These values can be any reasonable amount of ammunition greater than or equal to zero that each combatant TYPE might be expected to be able to carry.

The probability of kill for indirect fire ammunition is also an input parameter. This is applicable only to those combatant TYPEs that expend indirect fire ammunition. In this model, the artillery pieces of both forces are assumed to use only indirect fire ammunition. The LAV(AG)s and BMPs are assumed to possess a cannon and a coaxial machine gun. The cannon is assumed to be an indirect fire weapon that uses only indirect fire ammunition like that of artillery, and the coaxial machine gun is assumed to use the other class of ammunition which is the same as that used by the troops. Therefore, the troops of both forces will not have a probability of kill term, but the artillery and LAV(AG)s of both forces will. The values need not be the same for the Blue and Red forces. This parameter is used to calculate the amount of ammunition shot which is discussed later.

Two additional input parameters involve the TYPE 4 supply consideration of fuel. They are the fuel usage rate and the fuel tank capacity. The fuel usage rate is dimensioned in gallons per hour. The values used can be actual fuel usage rates found in appropriate equipment manuals or an estimate based on the scenario conditions. This model assumes that only the LAV(AG)s and BMPs will consume fuel. Fuel usage by vehicles towing artillery pieces will not be considered and is assumed to be zero. The fuel tank capacity is the actual maximum amount of fuel in gallons that a vehicle can hold. In this model, it is assumed to be zero for both TYPE 1 and TYPE 2 combatants for both the Blue and Red forces. As will be discussed, the fuel usage rates and the fuel tank capacities form a portion of the ammunition factor for TYPE 3 combatants.

The ammunition and fuel considerations contribute to the attrition rate coefficients of Equation 4.1 through the ammunition factors. Each combatant TYPE has its own coefficient, and it is calculated separately. TYPE 1 combatants (troops) use one class of ammunition that is a function of time and number of shooters. In realistic combat scenarios, if the ammunition available to shoot by each troop decreases, there is a tendency to conserve ammunition and shoot less frequently. If this effect is multiplied by the number of troops, the overall effect is a decrease in the number of enemy killed and a diminished fighting effectiveness. This model simulates this phenomena in three stages. If this ammunition available to shoot is above an internally calculated and continually updated value called the upper bound, then there exists an ammunition factor of 1. This ammunition factor is one of the terms that is multiplied to the original combat effectiveness which forms part of the attrition rate coefficient for the TYPE 1 combatants. When the ammunition factor is 1, there is no decrease in combat effectiveness due to ammunition. If the ammunition available to shoot falls below the upper bound, then the ammunition factor decreases to .6. This results in a combat effectiveness that is 60% of its former value. If the ammunition available to shoot falls below a lower bound, then the ammunition factor is decreased to .2. This results in a combat effectiveness that is 20% of its former value. This would be the case when the ammunition supply is very low and ammunition conservation is in full force. The upper and lower bounds can be modified by changing the selected values of 1, .6, and .2 which are internal to the main program. There are no fuel considerations for TYPE 1 combatants in this model.

TYPE 2 combatants (artillery) use the other class of ammunition labeled indirect fire ammunition. We will assume that this class of ammunition is expended strictly as a function of number of enemy targets killed. In realistic combat scenarios that utilize TYPE 2 combatants, once the effect of artillery has taken hold the number of enemy targets killed will rise substantially. In order to conserve ammunition, once these enemy casualties are realized the amount of expended ammunition has a tendency to decrease. For TYPE 2 combatants in this model, the ammunition factor (same as above) is a function of ammunition available. Ammunition available in turn is a function of ammunition shot and ammunition resupplied. It is assumed that the amount of ammunition shot is in direct proportion to the number of enemy combatants killed and inversely proportional to the probability of kill for indirect fire ammunition. As a result, the ammunition factor for TYPE 2 combatants is a

continually updated value ranging between zero and one. There are no fuel considerations for TYPE 2 combatants in this model.

TYPE 3 combatants (LAV(AG)s and BMPs) use both classes of ammunition. The ammunition expenditure rate for one class (coaxial machine gun ammunition) is assumed to be the same as that of TYPE 1 combatants and is calculated in exactly the same manner. The expenditure rate for the other class (indirect fire ammunition) is assumed to be the same as that of TYPE 2 combatants and is calculated in exactly the same manner. The TYPE 3 ammunition factor (different from above) is calculated partially from a combination of the expenditure rates of the two classes of ammunition and from the fuel factor which is discussed below.

TYPE 3 combatants are the only combatants in this model that demonstrate fuel usage considerations. In realistic combat scenarios, those items of equipment that require fuel to accomplish their missions generally do not have an unlimited fuel supply. It follows that as fuel supplies diminish the LAV(AG)s and BMPs will be forced to restrict their mobile operations which results in a reduced combat effectiveness. This model simulates this phenomena in three stages similar to that of the TYPE 1 ammunition expenditure calculations. It is assumed that the fuel available is a function of fuel used and fuel resupplied. Fuel used is a function of actual usage and amount of the ammunition fired. If the fuel available is greater than .8 times the fuel tank capacity, then the fuel factor is assumed to be equal to 1. If the fuel available is between .4 times the fuel tank capacity and .8 times the fuel tank capacity, then the fuel factor is assumed to be equal to .5. In this case, the combat effectiveness of the LAV(AG)s and BMPs would be decreased to 50% of its original value. If the fuel available is less than .4 times the fuel tank capacity the fuel factor is assumed to be .2 or equivalently a reduction in combat effectiveness of 80%. The fuel factor is then combined with the ammunition expenditure factors to form the ammunition factor for TYPE 3 combatants.

The sensitivity analysis characteristic is the same as that of the previous model except that there is an additional input parameter labeled rounds fired unit.second for the Blue and Red force TYPE 1 and TYPE 3 combatants. It is used only for those combatants expending suppressive fire ammunition. This parameter is the key factor in calculating the upper and lower bounds described previously where degradation of combat effectiveness is allowed due to the availability of ammunition. The parameter is a value between zero and one. As it gets smaller, more ammunition becomes

available which increases the ammunition factor and the combat effectiveness. The user enters values for this parameter as part of the sensitivity analysis characteristic.

Prior to modifying or expanding this model and the associated programs, the reader should carefully study the list of variables and the actual code in the computer programs provided at the end of the next section. Following the computer code line by line will help the user to understand the relationships just discussed.

D. THE COMPUTER PROGRAM AND ITS USE

One purpose of this section is to provide the user with the guidance necessary to run the computer programs for this model. Another purpose is to list and discuss the programming code in order to assist in the task of modifying this model to suit user specific needs.

The user's guidance presented below will clearly explain how to utilize the existing programs directly. It provides advanced knowledge of what to expect from the programs and how to reply to the prompts. It will also form a basis of guidance information for future programs that will likely require an even more extensive user's guide.

1. Load the input program by whatever name the user has given it. As with both previous models the input program must be run twice, one time for each force.
2. When the run command is executed, the reply will be "name of force = ?". Enter the name of the force and return.
3. The user will then be prompted only once for "time increment = ?". Enter the duration of time in minutes for each input time increment and return. This is a one time entry and represents the duration of time for each new input into the scenario.
4. The reply will be "enter #TYPE 1, #TYPE 2, #TYPE 3, #TYPE 4, #TYPE 5" on the first line, and on the next line the user will see "time = 0?" Enter the number or quantity of each TYPE without dimensions separated by commas and return. This represents the initial force strength and amount of combat essential supplies entering the scenario at time 0. The user will then see "time = _ ?". The blank represents the next time of input which is continually updated at each prompt by the amount of time equal to the time increment entered earlier. Enter the appropriate number or quantity for each TYPE as before and return. This represents the new force arrivals at the time in the scenario

indicated by the prompt. This cycle will continue until the user enters "-1" for TYPE 1 and then enters any values for the remaining four TYPEs and returns. This signifies the end of input for this force.

5. The reply will be the prompt "what is the effectiveness of our TYPE 1 against their TYPE 1, 2, 3?". Enter the appropriate combat effectiveness values greater than or equal to zero separated by commas and return. Refer to the previous section for the description and interpretation of combat effectiveness. The next two prompts will be the same as the one first described except that they will be for the users TYPE 2 and TYPE 3 combatants respectively against the opponents TYPE 1, TYPE 2, and TYPE 3 combatants. Enter the appropriate values as before and return in each case.
6. The reply will be the prompt "what is the proportion of time our TYPE 1 is used versus their TYPE 1, 2, 3?". Enter the appropriate proportions of time separated by commas and return. Each individual value must be in decimal form between zero and one, and the sum of the values must be less than or equal to one. Refer to the previous section for the description and interpretation of proportions of time. The next two prompts will be the same as the one just described except that they will be for the users TYPE 2 and TYPE 3 combatants respectively against the opponents TYPE 1, TYPE 2, and TYPE 3 combatants. Enter the appropriate values as before and return in each case.
7. The reply will be the prompt "what is the initial ammunition load of our TYPE 1, 2, 3?". This is the initial amount of ammunition (total rounds regardless of class) each entity of each combat TYPE will carry into the scenario at time 0. Enter values greater than or equal to zero separated by commas and return.
8. The reply will be the prompt "what is the proportion of ammo arriving intended for our TYPE 1, 2, 3?". This is the proportion of newly arriving ammunition separated into groups labeled by the combatant TYPEs that will be sent directly to the resupply point and stored by label until it is used by its respective combatant TYPE. The values must be in decimal form between zero and one, and they must sum to less than or equal to one. Enter the values separated by commas and return.
9. The reply will be the prompt "what is the predetermined amount of ammo to be shipped for our TYPE 1, 2, 3?". This is the predetermined amount of

ammunition that will be continuously force fed every input time increment to each of the combatant TYPEs. Enter the values greater than or equal to zero separated by commas and return.

10. The reply will be the prompt "what are the prob of kill for direct fire ammo for our TYPE 1, 2, 3,?". Enter the appropriate values between zero and one separated by commas and return.

11. The reply will be the prompt "what are the fuel usage rates per hour for our TYPE 1, 2, 3?". Enter the appropriate values greater than or equal to zero separated by commas and return.

12. The reply will be the prompt "what are the fuel tank capacities for our TYPE 1, 2, 3?". Enter the appropriate values greater than or equal to zero separated by commas and return.

13. The user must run the entire input program a second time for the opposing force. However, if the user desires to use the identical data for both forces such as in the illustration in this chapter, the user need only run the input program once, and then use the same file name when prompted in the main program for the name of the Blue and Red forces. The user can utilize the sensitivity analysis characteristic of the main program to introduce differences between the Blue and Red forces.

14. Load the main program.

15. When the run command is executed, the reply will be the display of a list of the available input files and the prompt "name of the Blue force=?". Enter the name of the file that applies to this program from those just displayed and return. The reply will be the prompt "name of the Red force=?". Enter the name of the file that applies to this program from those just displayed and return.

16. The reply will be a display of the Blue and Red force inputs and the statement "current Blue multiplier= 1", and on the next line the prompt will be "new value=?". Input the desired multiplier greater than zero and return. The reply will be the statement "current Red multipler= 1", and on the next line the prompt will be "new value=?". Input the desired multiplier greater than zero and return.

17. The reply will be the statement "current Blue TYPE1 rounds fired/unit sec= 0", and on the next line the prompt will be "new value=?". Input the desired

value in decimal form between zero and one and return. The reply will be the statement "current Red TYPE1 rounds fired/unit/sec= 0", and on the next line the prompt will be "new value=?". Input the desired value in decimal form between zero and one and return. The reply will be the statement "current Blue TYPE3 rounds fired/unit/sec= 0", and on the next line the prompt will be "new value=?". Input the desired value in decimal form between zero and one and return. The reply will be the statement "current Red TYPE3 rounds fired/unit/sec= 0", and on the next line the prompt will be "new value=?". Input the desired value in decimal form between zero and one and return. Refer to the previous section for a discussion of this parameter.

18. The reply will be a display of blocks of output by increasing input time increments in 5 columns labeled "SIDE", "TIME", "TYPE1", "TYPE2", and "TYPE3". The run will stop when the last TYPE strength of one force equals zero. That force has been annihilated.
19. The reply will be "another run?" Entering "no" and returning will end the program run. Entering "yes" and returning will cause a return to the line in the program that allows new inputs for the Blue and Red force sensitivity analysis factors. Changing these values and continuing with the program allows the user to conduct as much of a sensitivity analysis as desired.

A list of variables is provided in Table 7. Note that the number of variables used in this model is considerably larger than that of the first two models. This is due to the use of differing combatant TYPEs and the number of logistics and resupply considerations for each of them. The reader should be aware that as this model is expanded, the requirement for additional variables becomes greater. For example, if the total number of TYPEs utilized is doubled from five to ten, the number of variables required will nearly double. This is assuming that no additional logistics or resupply considerations need to be modeled. The point here is that the user should be conservative in the total number of TYPEs used, or programming the model may get out of hand.

With the exception of the sensitivity analysis characteristics, all the parameters and resupply considerations are provided for the main program by utilizing the input program in Table 8. As a result the length of the input program for this model is considerably longer and more complex than those of the two previous models. If additional logistics or resupply considerations need to be modeled, it is recommended

that their respective inputs be added to an input program similar to that of Table 8. This will reduce the congestion of the main program and retain program modification flexibility. For example, suppose one additional combatant, say TYPE 6 which might be similar to that of the current TYPE 3, needed to be added to the scenario. This could easily be accomplished by adding a "TYPE 6" term to the quantity to be entered per input time increment line. Two additional blocks of code for effectiveness and proportion of time would have to be added, but they would be identical in form to those already in the input program. Also there would have to be one additional term and variable added to each of the remaining logistics considerations. Suppose instead that one additional supply consideration needed to be added. This could be accomplished by adding one more block of code prior to the close statement of the input program. The new block of code would be of the same form as the others currently in the input program. It would also be necessary to add the new consideration to the input reading sections and to the appropriate equations in the main program.

The main program for this model is presented in its entirety in Table 9. The reader should note how blocks of related code are grouped together and labeled. This was done in order to simplify the task of program modification. For example, suppose one additional combatant say TYPE 6 were to be added to the program, and it had similar logistics requirements to that of the current TYPE 3 combatant. Lines of code identical to those for the Blue and Red force logistics and effectiveness calculations would have to be reproduced, but the only difference would be using different variable names to represent the new combatant TYPE. The new blocks of code would have to be inserted into the main program in the vicinity of those for the Blue and Red TYPE 3 combatants. If the new TYPE 6 combatant had a delayed resupply configuration as described in the previous section, then the blocks of code for the new TYPE 6 combatant would have to be inserted into the main program in the vicinity of the Blue and Red TYPE 2 combatants. In either case, additional terms would have to be added where appropriate in sections prior to the main program loop and in the output coding. Minor adjustments would also have to be made to the input program as described previously.

A key point about the input and main computer programs for this model is that they do not have to be completely rewritten when being modified. Generally speaking, additions and deletions can be made by adding or deleting entire blocks of similar code

to those already present in the programs. Many of the supply considerations of major importance can be fit into one of the methods shown in the main program. For example, if water were to be added as an additional supply support consideration, it could be modeled in the same manner as that of fuel usage except that the lines of code representing water considerations would have to be added to all the combatant TYPEs not just one as fuel is for TYPE 3 combatants. Should the user decide to model other supply support considerations with methods not shown in this model, it is recommended that they be coded together in a similar manner to that demonstrated in this program.

TABLE 7

LIST OF VARIABLES FOR THE THIRD MODEL MAIN PROGRAM

```
B$   - Character variable name for Blue force
R$   - Character variable name for Red force
Y$   - Character variable response to "another run?"
B    - Two dimensional array for Blue TYPE input
I    - Counter
J    - Main loop control in steps of 1 second
K    - Counter
R    - Two dimensional array for Red TYPE input
T    - Input time increment
BF   - Blue prevention factor of B=-1
BK   - Array total Blue killed for time increment
BT   - Two dimensional array of proportion of time Blue TYPE
       1,2,3 versus Red TYPE 1,2,3
CL   - Red combat effectiveness multiplier
EB   - Two dimensional array of Blue TYPE 1,2,3
       effectiveness versus Red TYPE 1,2,3
ER   - Two dimensional array of Red TYPE 1,2,3
       effectiveness versus Blue TYPE 1,2,3
KL   - Blue combat effectiveness multiplier
RF   - Red prevention factor of R=-1
RK   - Array Red killed per time increment
RT   - Two dimensional array of proportion of time Red TYPE
       1,2,3 versus Blue TYPE 1,2,3
TB   - Array Blue running total # of arrivals per TYPE
TR   - Array Red running total # of arrivals per TYPE
UP   - Update variable
B1   - Array Blue # remaining by TYPE per time increment
C1   - Red multiplier input
D1   - Temporary variable
E1   - Temporary variable
I1   - Counter
J1   - Counter
K1   - Blue multiplier input
R1   - Array Red # remaining by TYPE per time increment
BAF  - Array Blue ammo factor by TYPE
BAT  - Array for Blue proportion ammo arrivals to TYPE ( )
BIJ  - Two dimensional array # Blue of TYPE I1 killed by Red
       TYPE J1
RAF  - Array Red ammo factor by TYPE
RAT  - Array for Red proportion ammo arriving to TYPE ( )
RIJ  - Two dimensional array # Red of TYPE I1 killed by Blue
       TYPE J1
BF3  - Blue amount fuel at storage point for TYPE 3
DB2  - Blue # killed per time increment by Red TYPE 2
DB3  - Blue # killed per time increment by Red TYPE 3
DR2  - Red # killed per time increment by Blue TYPE 2
DR3  - Red # killed per time increment by Blue TYPE 3
RF3  - Red amount fuel at storage point for TYPE 3
TV1  - Temporary variable
TV2  - Temporary variable
BNEW- Array Blue # new arrivals by TYPE
RNEW- Array Red # new arrivals by TYPE
BAC2- Blue total ammo capacity for all TYPE 2
BAM1- Blue rounds ammo fired/time increment/TYPE 1 shooter
BAM3- Blue rounds ammo fired/time increment/TYPE 3 shooter
BFC1- Blue fuel tank capacity for TYPE 1
BFC2- Blue fuel tank capacity for TYPE 2
BFC3- Blue fuel tank capacity for TYPE 3
BFU1- Blue hourly fuel usage rate for TYPE 1
BFU2- Blue hourly fuel usage rate for TYPE 2
BFU3- Blue hourly fuel usage rate for TYPE 3
BIL1- Blue initial load for TYPE 1
BIL2- Blue initial load for TYPE 2
```

TABLE 7

LIST OF VARIABLES FOR THE THIRD MODEL MAIN PROGRAM (CONT'D.)

BIL3- Blue initial load for TYPE 3
BPK1- Blue prob of kill for indirect fire ammo for TYPE 1
BPK2- Blue prob of kill for indirect fire ammo for TYPE 2
BPK3- Blue prob of kill for indirect fire ammo for TYPE 3
BSP1- Blue ammo resupply to TYPE 1
BSP2- Blue ammo resupply to TYPE 2
BSP3- Blue ammo resupply to TYPE 3
RAC2- Red total ammo capacity for all TYPE 2
RAM1- Red rounds ammo fired/time increment/TYPE 3 shooter
RAM3- Red rounds ammo fired/time increment/TYPE 3 shooter
RFC1- Red fuel tank capacity for TYPE 1
RFC2- Red fuel tank capacity for TYPE 2
RFC3- Red fuel tank capacity for TYPE 3
RFU1- Red hourly fuel usage rate for TYPE 1
RFU2- Red hourly fuel usage rate for TYPE 2
RFU3- Red hourly fuel usage rate for TYPE 3
RIL1- Red initial load for TYPE 1
RIL2- Red initial load for TYPE 2
RIL3- Red initial load for TYPE 3
RPK1- Red prob of kill for indirect fire ammo for TYPE 1
RPK2- Red prob of kill for indirect fire ammo for TYPE 2
RPK3- Red prob of kill for indirect fire ammo for TYPE 3
RSP1- Red ammo resupply to TYPE 1
RSP2- Red ammo resupply to TYPE 2
RSP3- Red ammo resupply to TYPE 3
BTEMP-Array temporary storage # Blue by TYPE
RTEMP-Array temporary storage # Red by TYPE
BAMO1-Blue amount of ammo for TYPE 1 at resupply point
BAMO2-Blue amount of ammo for TYPE 2 at resupply point
BAMO3-Blue amount of ammo for TYPE 3 at resupply point
BASH1-Blue ammo shot by TYPE 1
BASH2-Blue ammo shot by TYPE 2
BASH3-Blue ammo shot by TYPE 3
BFAV3-Blue amount fuel left in fuel tank of TYPE 3
BFSP3-Blue amount fuel supplied to TYPE 3
BFUP3-Blue amount fuel used up by TYPE 3
BORD2-Blue ammo ordered for TYPE 2
BRSP1-Blue predetermined ammo to be shipped to TYPE 1
BRSP2-Blue predetermined ammo to be shipped to TYPE 2
BRSP3-Blue predetermined ammo to be shipped to TYPE 3
RAMO1-Red amount of ammo for TYPE 1 at resupply point
RAMO2-Red amount of ammo for TYPE 2 at resupply point
RAMO3-Red amount of ammo for TYPE 3 at resupply point
RASH1-Red ammo shot by TYPE 1
RASH2-Red ammo shot by TYPE 2
RASH3-Red ammo shot by TYPE 3
RFAV3-Red amount fuel left in fuel tank of TYPE 3
RFSP3-Red amount fuel supplied to TYPE 3
RFUP3-Red amount fuel used up by TYPE 3
RORD2-Red ammo ordered for TYPE 2
RRSP1-Red predetermined ammo to be shipped to TYPE 1
RRSP2-Red predetermined ammo to be shipped to TYPE 2
RRSP3-Red predetermined ammo to be shipped to TYPE 3
BAMAV1-Blue ammo available for TYPE 1
BAMAV2-Blue ammo available for TYPE 2
BAMAV3-Blue ammo available for TYPE 3
BTEMP3-Blue number rounds fired for TYPE 3
RAMAV1-Red ammo available for TYPE 1
RAMAV2-Red ammo available for TYPE 2
RAMAV3-Red ammo available for TYPE 3
RTEMP3-Red number rounds fired for TYPE 3

TABLE 8

INPUT PROGRAM FOR THE THIRD MODEL

```
10 INPUT "name of FORCE=",A$
20 INPUT "time increment=",T
30 OPEN "b:"+A$ FOR OUTPUT AS #1
40 PRINT #1,T
50 PRINT "enter #TYPE 1, #TYPE 2, #TYPE 3, #TYPE 4, #TYPE 5"
60 FOR I=0 TO 99
70 PRINT "time=";I*T;
80 INPUT A1,A2,A3,A4,A5
90 PRINT #1,A1,A2,A3,A4,A5
100 IF A1<0 THEN 140
110 NEXT I
120 PRINT "what is the EFFECTIVENESS of our TYPE 1 ";
130 PRINT "against their TYPE 1,2,3?";
140 INPUT X1,X2,X3
150 PRINT #1,X1/(T*60),X2/(T*60),X3/(T*60)
160 PRINT "what is the EFFECTIVENESS of our TYPE 2 ";
170 PRINT "against their TYPE 1,2,3?";
180 INPUT X1,X2,X3
190 PRINT #1,X1/(T*60),X2/(T*60),X3/(T*60)
200 PRINT "what is the EFFECTIVENESS of our TYPE 3 ";
210 PRINT "against their TYPE 1,2,3?";
220 INPUT X1,X2,X3
230 PRINT #1,X1/(T*60),X2/(T*60),X3/(T*60)
240 PRINT "what is the PROPORTION OF TIME our TYPE 1 ";
250 PRINT "is used versus their TYPE 1,2,3?";
260 INPUT X1,X2,X3
270 PRINT #1,X1,X2,X3
280 PRINT "what is the PROPORTION OF TIME our TYPE 2 ";
290 PRINT "is used versus their TYPE 1,2,3?";
300 INPUT X1,X2,X3
310 PRINT #1,X1,X2,X3
320 PRINT "what is the PROPORTION OF TIME our TYPE 3 ";
330 PRINT "is used versus their TYPE 1,2,3?";
340 INPUT X1,X2,X3
350 PRINT #1,X1,X2,X3
360 PRINT "what is the INITIAL AMMUNITION ";
370 PRINT "LOAD of our TYPE 1,2,3?";
380 INPUT X1,X2,X3
390 PRINT #1,X1,X2,X3
400 PRINT "what is the PROPORTION OF AMMO ARRIVING ";
410 PRINT "intended for our TYPE 1,2,3?";
420 INPUT X1,X2,X3
430 PRINT #1,X1,X2,X3
440 PRINT "what is the PREDETERMINED AMOUNT OF AMMO ";
450 PRINT "TO BE SHIPPED for our TYPE 1,2,3?";
460 INPUT X1,X2,X3
470 PRINT #1,X1,X2,X3
480 PRINT "what are the PROB OF KILL for direct fire ammo ";
490 PRINT "for our TYPE 1,2,3?";
500 INPUT X1,X2,X3
510 PRINT #1,X1,X2,X3
520 PRINT "what are the FUEL USAGE RATES per hour ";
530 PRINT "for our TYPE 1,2,3?";
540 INPUT X1,X2,X3
550 PRINT #1,X1/(3600),X2/(3600),X3/(3600)
560 PRINT "what are the FUEL TANK CAPACITIES ";
570 PRINT "for our TYPE 1,2,3?";
580 INPUT X1,X2,X3
590 PRINT #1,X1,X2,X3
600 CLOSE
610 END
```

TABLE 9

MAIN PROGRAM FOR THE THIRD MODEL

```
10 FILES "b:
20 '
30 '*****ARRAY DIMENSIONS*****
40 '
50 DIM B(100,5),R(100,5)
60 DIM EB(3,3),ER(3,3)
70 DIM BT(3,3),RT(3,3)
80 DIM BIJ(3,3),RIJ(3,3)
90 DIM BTEMP(3),RTEMP(3)
100 DIM BNEW(3),RNEW(3)
110 DIM B1(3),R1(3)
120 DIM BK(3),RK(3)
130 DIM BAT(3),RAT(3)
140 DIM TB(3),TR(3)
150 '
160 '*****FORCE AND FILE IDENTIFICATION*****
170 '
180 INPUT "name of the BLUE FORCE=";B$
190 INPUT "name of the RED FORCE=";R$
200 '
210 '*****READS BLUE INPUT FROM INPUT PROGRAM*****
220 '
230 OPEN "b:"+B$ FOR INPUT AS #1
240 INPUT #1,T
250 PRINT "BLUE INPUT"
260 FOR I=0 TO 100
270     INPUT #1,B(I,1),B(I,2),B(I,3),B(I,4),B(I,5)
280     IF B(I,1)<0 THEN 310
290     PRINT I*T,B(I,1),B(I,2),B(I,3),B(I,4),B(I,5)
300 NEXT I
310 FOR I=1 TO 3
320     INPUT #1,EB(I,1),EB(I,2),EB(I,3)
330 NEXT I
340 FOR I=1 TO 3
350     INPUT #1,BT(I,1),BT(I,2),BT(I,3)
360 NEXT I
370 INPUT #1,BIL1,BIL2,BIL3
380 INPUT #1,BAT(1),BAT(2),BAT(3)
390 INPUT #1,BRSP1,BRSP2,BRSP3
400 INPUT #1,BPK1,BPK2,BPK3
410 INPUT #1,BFU1,BFU2,BFU3
420 INPUT #1,BFC1,BFC2,BFC3
430 CLOSE 1
440 '
450 '*****READS RED INPUT FROM INPUT PROGRAM*****
460 '
470 OPEN "b:"+R$ FOR INPUT AS #1
480 INPUT #1,T
490 PRINT "RED INPUT"
500 FOR I=0 TO 100
510     INPUT #1,R(I,1),R(I,2),R(I,3),R(I,4),R(I,5)
520     IF R(I,1)<0 THEN 550
530     PRINT I*T,R(I,1),R(I,2),R(I,3),R(I,4),R(I,5)
540 NEXT I
550 FOR I=1 TO 3
560     INPUT #1,ER(I,1),ER(I,2),ER(I,3)
570 NEXT I
580 FOR I=1 TO 3
590     INPUT #1,RT(I,1),RT(I,2),RT(I,3)
600 NEXT I
610 INPUT #1,RIL1,RIL2,RIL3
```

TABLE 9

MAIN PROGRAM FOR THE THIRD MODEL (CONT'D.)

```
620 INPUT #1,RAT(1),RAT(2),RAT(3)
630 INPUT #1,RRSP1,RRSP2,RRSP3
640 INPUT #1,RPK1,RPK2,RPK3
650 INPUT #1,RFU1,RFU2,RFU3
660 INPUT #1,RFC1,RFC2,RFC3
670 CLOSE 1
680 '
690 '****MULTIPLICATION FACTORS FOR SENSITIVITY ANALYSIS****
700 '
710 CL=1:KL=1:BAM1=0:RAM1=0:BAM3=0:RAM3=0
720 BORD2=.5:RORD2=.5
730 PRINT "current BLUE MULTIPLIER=";KL
740 INPUT "new value=";K1
750 IF K1<>0 THEN KL=K1
760 PRINT "current RED MULTIPLIER=";CL
770 INPUT "new value=";C1
780 IF C1<>0 THEN CL=C1
790 PRINT "current BLUE TYPE1 ROUNDS FIRED/UNIT/SEC=";BAM1
800 INPUT "new value=";D1
810 IF D1<>0 THEN BAM1=D1
820 PRINT "current RED TYPE1 ROUNDS FIRED/UNIT/SEC=";RAM1
830 INPUT "new value=";E1
840 IF E1<>0 THEN RAM1=E1
850 PRINT "current BLUE TYPE3 ROUNDS FIRED/UNIT/SEC=";BAM3
860 INPUT "new value=";D3
870 IF D3<>0 THEN BAM3=D3
880 PRINT "current RED TYPE3 ROUNDS FIRED/UNIT/SEC=";RAM3
890 INPUT "new value=";E3
900 IF E3<>0 THEN RAM3=E3
910 '
920 '*****INITIALIZATIONS*****
930 '
940 FOR K=1 TO 3
950    B1(K)=B(0,K)
960    R1(K)=R(0,K)
970    TB(K)=B1(K)
980    TR(K)=R1(K)
990 NEXT K
1000 BAMAV1=BIL1*B1(1):RAMAV1=RIL1*R1(1)
1010 BAMAV2=BIL2*B1(2):RAMAV2=RIL2*R1(2)
1020 BAMAV3=BIL3*B1(3):RAMAV3=RIL3*R1(3)
1030 BAMO1=BAT(1)*B(0,5):RAMO1=RAT(1)*R(0,5)
1040 BAF(2)=1:RAF(2)=1
1050 BAF(3)=1:RAF(3)=1
1060 BFAV3=BFC3*B1(3):RFAV3=RFC3*R1(3)
1070 BF3=B(0,4):RF3=R(0,4)
1080 BF=1:RF=1
1090 I=0:UP=1
1100 '
1110 '*****MAIN PROGRAM LOOP*****
1120 '
1130 FOR J=0 TO 36000!
1140    IF UP=1 THEN 2760
1150    UP=0
1160    IF J=I*T*60 THEN UP=1
1170    X$=INKEY$:IF X$<>"" THEN 2900
1180    '
1190    '***STORES OUTPUT OF PREVIOUS TIME THRU LOOP***
1200    '
1210    FOR K=1 TO 3
1220       RTEMP(K)=R1(K)
```

TABLE 9

MAIN PROGRAM FOR THE THIRD MODEL (CONT'D.)

```
1230       BTEMP(K)=B1(K)
1240       RNEW(K)=R(I,K)*UP
1250       BNEW(K)=B(I,K)*UP
1260       RK(K)=0:BK(K)=0
1270    NEXT K
1280    '
1290    '***END OF SERIAL DATA INPUT CHECK***
1300    '
1310    IF (R(I,1)*UP)<0 THEN RF=0
1320    IF (B(I,1)*UP)<0 THEN BF=0
1330    IF UP=0 THEN 1450
1340    BAMAV1=BAMAV1+BNEW(1)*BF*BIL1
1350    BAMAV2=BAMAV2+BNEW(2)*BF*BIL2
1360    BAMAV3=BAMAV3+BNEW(3)*BF*BIL3
1370    BFAV3=BFAV3+BNEW(3)*BF*BFC3
1380    RAMAV1=RAMAV1+RNEW(1)*RF*RIL1
1390    RAMAV2=RAMAV2+RNEW(2)*RF*RIL2
1400    RAMAV3=RAMAV3+RNEW(3)*RF*RIL3
1410    RFAV3=RFAV3+RNEW(3)*RF*RFC3
1420    '
1430    '***BLUE TYPE 1 LOG. AND EFFECT. CALCULATIONS***
1440    '
1450    IF BAMAV1>3*BTEMP(1)*BAM1 THEN BAF(1)=1:GOTO 1480
1460    IF BAMAV1>2*BTEMP(1)*BAM1 THEN BAF(1)=.6:GOTO 1480
1470    BAF(1)=.2
1480    BASH1=BTEMP(1)*BAM1*BAF(1)
1490    BAMAV1=BAMAV1-BASH1+BSP1*UP
1500    IF BAMO1>=BRSP1 THEN BSP1=BRSP1 ELSE BSP1=BAMO1
1510    BAMO1=BAMO1-BSP1+B(I,5)*BAT(1)*BF*UP
1520    '
1530    '***RED TYPE 1 LOG. AND EFFECT. CALCULATIONS***
1540    '
1550    IF RAMAV1>3*RTEMP(1)*RAM1 THEN RAF(1)=1:GOTO 1580
1560    IF RAMAV1>2*RTEMP(1)*RAM1 THEN RAF(1)=.6:GOTO 1580
1570    RAF(1)=.2
1580    RASH1=RTEMP(1)*RAM1*RAF(1)
1590    RAMAV1=RAMAV1-RASH1+RSP1*UP
1600    IF RAMO1>=RRSP1 THEN RSP1=RRSP1 ELSE RSP1=RAMO1
1610    RAMO1=RAMO1-RSP1+R(I,5)*RAT(1)*RF*UP
1620    '
1630    '***BLUE TYPE 3 LOG. AND EFFECT. CALCULATIONS***
1640    '
1650    IF BAMAV3>3*BTEMP(3)*BAM3 THEN BAF(3)=1:GOTO 1680
1660    IF BAMAV3>2*BTEMP(3)*BAM3 THEN BAF(3)=.6:GOTO 1680
1670    BAF(3)=.2
1680    BASH3=BTEMP(3)*BAM3*BAF(3)
1690    DR3=0
1700    FOR K=2 TO 3
1710       DR3=DR3+RIJ(K,3)
1720    NEXT K
1730    BTEMP3=DR3/BPK3
1740    BFUP3=BFU3*BTEMP(3)+BTEMP3*.1
1750    BFAV3=BFAV3-BFUP3+BFSP3*UP
1760    IF BFAV3>.8*BFC3 THEN BFF3=1:GOTO 1790
1770    IF BFAV3>.4*BFC3 THEN BFF3=.5:GOTO 1790
1780    BFF3=.2
1790    BASH3=BASH3+BTEMP(3)
1800    BAMAV3=BAMAV3-BASH3+BSP3*UP
1810    BAF(3)=BAF(3)*BFF3
1820    IF UP=0 GOTO 1900
1830    IF BAMO3>=BRSP3 THEN BSP3=BRSP3 ELSE BSP3=BAMO3
```

TABLE 9

MAIN PROGRAM FOR THE THIRD MODEL (CONT'D.)

```
1840    BAMO3=BAMO3-BSP3+B(I,5)*BAT(3)*BF*UP
1850    IF BF3>=BFUP3 THEN BFSP3=BFUP3 ELSE BFSP3=BF3
1860    BF3=BF3-BFSP3+B(I,4)*BF*UP
1870    '
1880    '***RED TYPE 3 LOG. AND EFFECT. CALCULATIONS***
1890    '
1900    IF RAMAV3>3*RTEMP(3)*RAM3 THEN RAF(3)=1:GOTO 1930
1910    IF RAMAV3>2*RTEMP(3)*RAM3 THEN RAF(3)=.6:GOTO 1930
1920    RAF(3)=.2
1930    RASH3=RTEMP(3)*RAM3*RAF(3)
1940    DB3=0
1950    FOR K=2 TO 3
1960       DB3=DB3+BIJ(K,3)
1970    NEXT K
1980    RTEMP3=DB3/RPK3
1990    RFUP3=RFU3*RTEMP(3)+RTEMP3*.1
2000    RFAV3=RFAV3-RFUP3+RFSP3*UP
2010    IF RFAV3>.8*RFC3 THEN RFF3=1:GOTO 2040
2020    IF RFAV3>.4*RFC3 THEN RFF3=.5:GOTO 2040
2030    RFF3=.2
2040    RASH3=RASH3+RTEMP(3)
2050    RAMAV3=RAMAV3-RASH3+RSP3*UP
2060    RAF(3)=RAF(3)*RFF3
2070    IF UP=0 GOTO 2150
2080    IF RAMO3>=RRSP3 THEN RSP3=RRSP3 ELSE RSP3=RAMO3
2090    RAMO3=RAMO3-RSP3+R(I,5)*RAT(3)*RF*UP
2100    IF RF3>=RFUP3 THEN RFSP3=RFUP3 ELSE RFSP3=RF3
2110    RF3=RF3-RFSP3+R(I,4)*RF*UP
2120    '
2130    '***LANCHESTER EQUATIONS AND CALCULATIONS***
2140    '
2150    FOR I1=1 TO 3
2160     FOR J1=1 TO 3
2170      RIJ(I1,J1)=BT(J1,I1)*EB(J1,I1)*BTEMP(J1)*KL*BAF(J1)
2180      BIJ(I1,J1)=RT(J1,I1)*ER(J1,I1)*RTEMP(J1)*CL*RAF(J1)
2190      BK(I1)=BK(I1)+BIJ(I1,J1)
2200      RK(I1)=RK(I1)+RIJ(I1,J1)
2210     NEXT J1
2220    NEXT I1
2230    '
2240    '***BLUE TYPE 2 LOG. AND EFFECT. CALCULATIONS***
2250    '
2260    DR2=0
2270    FOR K=1 TO 3
2280       DR2=DR2+RIJ(K,2)
2290    NEXT K
2300    BASH2=DR2/BPK2
2310    BAMAV2=BAMAV2-BASH2+BSP2*UP
2320    IF BAMAV2<0 THEN BAMAV2=0
2330    BAC2=BIL2*BTEMP(2)
2340    IF BAMAV2<BAC2 THEN BAF(2)=BAMAV2/BAC2 ELSE BAF(2)=1
2350    IF (BAMAV2<=BORD2*BAC2) AND UP=1 THEN 2370
2360    GOTO 2380
2370    IF BAMO2>=BRSP2 THEN BSP2=BRSP2 ELSE BSP2=BAMO2
2380    BAMO2=BAMO2-BSP2+B(I,5)*BAT(2)*BF*UP
2390    '
2400    '***RED TYPE 2 LOG. AND EFFECT. CALCULATIONS***
2410    '
2420    DB2=0
2430    FOR K=1 TO 3
2440       DB2=DB2+BIJ(K,2)
```

TABLE 9

MAIN PROGRAM FOR THE THIRD MODEL (CONT'D.)

```
2450     NEXT K
2460     RASH2=DB2/RPK2
2470     RAMAV2=RAMAV2-RASH2+RSP2*UP
2480     IF RAMAV2<0 THEN RAMAV2=0
2490     RAC2=RIL2*RTEMP(2)
2500     IF RAMAV2<RAC2 THEN RAF(2)=RAMAV2/RAC2 ELSE RAF(2)=1
2510     IF (RAMAV2<=RORD2*RAC2) AND UP=1 THEN 2530
2520     GOTO 2540
2530     IF RAMO2>=RRSP2 THEN RSP2=RRSP2 ELSE RSP2=RAMO2
2540     RAMO2=RAMO2-RSP2+R(I,5)*RAT(2)*RF*UP
2550     '
2560     '***STRENGTH CALCULATIONS***
2570     '
2580     FOR K=1 TO 3
2590        R1(K)=RTEMP(K)+RNEW(K)*RF*UP-RK(K)
2600        IF R1(K)<0 THEN R1(K)=0
2610        B1(K)=BTEMP(K)+BNEW(K)*BF*UP-BK(K)
2620        IF B1(K)<0 THEN B1(K)=0
2630     NEXT K
2640     FOR K=1 TO 3
2650        TR(K)=TR(K)+RNEW(K)*RF*UP
2660        TB(K)=TB(K)+BNEW(K)*BF*UP
2670     NEXT K
2680     IF UP=0 THEN 2890
2690     '
2700     '***PRINTS OUTPUT***
2710     '
2720   FOR K=1 TO 3
2730   B1(K)=INT(B1(K)+.5)
2740   R1(K)=INT(R1(K)+.5)
2750   NEXT K
2760   PRINT
2770   PRINT "SIDE","TIME","TYPE1","TYPE2","TYPE3"
2780   PRINT "blue",T*I,INT(B1(1)),INT(B1(2)),INT(B1(3))
2790   PRINT "blue","dead",INT(TB(1)-B1(1)),INT(TB(2)-B1(2));
2800   PRINT " ",INT(TB(3)-B1(3))
2810   PRINT "red",T*I,INT(R1(1)),INT(R1(2)),INT(R1(3))
2820   PRINT "red","dead",INT(TR(1)-R1(1)),INT(TR(2)-R1(2));
2830   PRINT " ",INT(TR(3)-R1(3))
2840   PRINT
2850   I=I+1:UP=0
2860   TV1=INT(R1(1)+R1(2)+R1(3))
2870   TV2=INT(B1(1)+B1(2)+B1(3))
2880   IF (TV1=0 OR TV2=0) AND RF+BF=0 THEN 2900
2890 NEXT J
2900 INPUT "another run?";Y$
2910 IF Y$="y" OR Y$="Y" THEN 730
2920 END
```

V. CONCLUSIONS

A. ADDITIONAL CONSIDERATIONS

In some cases, it may be desirable to include graphics with the output. For example, the output of Figure 4.1 could be sent to a graphics program and displayed in any of a number of fashions such as curves or histograms. Several different parameters of the hypothetical scenario could also be displayed. For example, Blue and Red force strengths or losses could be plotted versus time. Ammunition expenditure rates or fuel usage rates could be plotted versus time or combatant TYPE. It may also be worthwhile to plot several sets of program runs with slightly different parameter inputs to detect trends in a given class of combat scenarios.

Another consideration is that of combining concepts of the three models and the two intermediary steps discussed in this thesis. The two intermediary steps used to arrive at the third model were briefly discussed at the beginning of Chapter 4. In order to reduce redundancy, they were not presented in their entirety as the third model incorporates all of their important advantages and considerations. However, the user may want to explore them further. For example, a situation may arise where the user might want to use the properties of the first model with the addition of multiple combat TYPEs. This would involve the merging of the first model with the ideas discussed in the first intermediary step resulting in a new model. It may also be desirable to utilize the properties of the first model with the addition of multiple combat TYPEs and proportions of engagement time which would be a merging of the first model and the ideas of the second intermediary step. There could also be a merging of the second model with the ideas of each of the intermediary steps resulting in yet two more new models. The combining of features of various models or of entirely new concepts is suggested to develop alternate models for other applications.

A third consideration is that of transforming the models from a "who's going to win" result to a "what do I have to do to win" result. This idea would be similar to that of optimization. Recall the scenario of the illustration for the first model and the results of Figure 2.1. The Blue force commander had been annihilated at time 40, and the Red force had 354 troops remaining. This result did not prove satisfactory to the Blue force commander, and adjustments were made to the scenario resulting in the

output of Figure 2.2. This was more favorable to the Blue force commander. If these adjustments had not been favorable to the Blue force commander, then additional adjustments would have been made and this procedure would have continued until favorable results would have been obtained for the Blue force commander. Instead of picking a parameter to change and continually updating that parameter based on the output of program runs, it would be more advantageous to run the program once and have the output tell the commander or user what has to be changed in order to obtain a specific outcome. Consider the case where a run of a program resulted in the output of Figure 2.1. Suppose that the Blue force commander now wanted to know how many additional troops he would have to add to the scenario in order to defeat the same Red force. The first model could be modified into an optimization model for this purpose. An additional loop would have to be added to surround the main program loop in Table 4. This additional loop would also be incremented by one second time steps, and its purpose would be to take the strength of the Red force and continually add Blue combatants to the scenario until both forces were annihilated or until there exists an acceptable number of Blue combatants remaining. This technique will not be presented in this thesis; rather it is suggested for future research. Another area of future research might be that of improving the numerical solution method.

B. SUMMARY

A brief overview of the importance of logistics was discussed, and three force on force combat attrition models were presented. Each of the three models were based on modified Lanchester theory, and they each demonstrated a different method of incorporating logistics or combat essential supplies into the Lanchester attrition process. All of the models were designed for small unit short term scenarios ranging from firefights similar to what was common in Vietnam to those as big as the operation in Grenada. The intent of this thesis was to provide a basis for a logistics combat modeling capability for such kinds of engagements at the small unit level without utilizing mainframe computers or large scale complex models. The models and computer programs presented in this thesis can be modified to suit user specific needs at the small unit level.

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